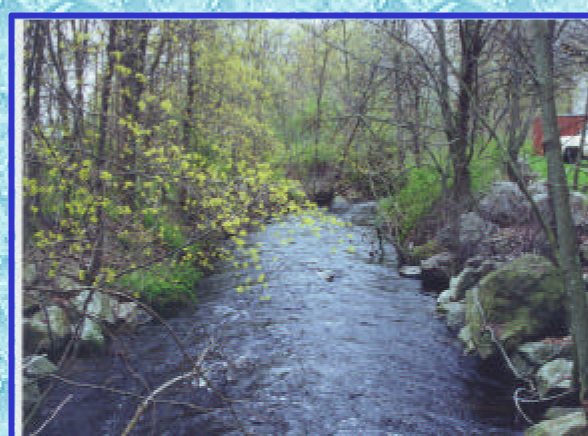
Massachusetts Department of Environmental Management

Saugus River Water Budget and Instream Flow Study



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Final Report, June 2002

Executive Summary

Background

The Executive Office of Environmental Affairs Watershed Initiative North Coastal Basin Team commissioned a study to evaluate the relationship between streamflow regulation in the Saugus River and aquatic habitat needs. The Saugus River is a small coastal stream located north of Boston, MA. The watershed is approximately 23.3 square miles.

The Saugus River is located in an urban area and has been impacted by human activities for over 300 years. Several public water supply sources are located in the Saugus River Basin. Most of the water removed from the river directly, or indirectly from groundwater sources and ponds does not return to the basin, rather it is discharged out of basin to wastewater treatment facilities. In addition, development has altered wetlands, culverted the river beneath major roads, and placed barriers such as dams across the river. Surface water features in the watershed are manipulated for flood control. The magnitude and timing of river flow has been altered as a result of these human activities. Despite its location in a heavily developed urban area, large tracts of open space remain along the river corridor, including golf courses, state reservations, a national park, and vast areas of protected wetlands. Available data suggest the river water quality is suitable to maintain a warm-water fishery and an inspection shows that fish passage is available along the approximately five river miles from the fresh-water limit near the Saugus Ironworks to the Lynn Water and Sewer Commission Diversion Dam[1] at the Sheraton golf course in Wakefield. Historic records indicate a once-prolific alewife run took place in the Saugus River annually. Recent surveys show a lack of a thriving fish population in the river, however. This study determined that although natural flow conditions probably did not provide optimal fish habitat, improvements to the timing and magnitude of flow could be made to increase fish populations in the river as well as improve water quality. The impacts of past human development cannot be undone; water resources must be reasonably allocated among human and environmental needs. Opportunities exist to improve aquatic habitat by managing river flow. Even modest modifications toward the natural flow regime (such as maintaining seasonal minimum flows throughout the year) may result in vast improvements in fish populations and habitation of the river. This in turn will support a healthy watershed ecosystem.

Understanding Hydrology- Regulated Flow and Estimated Unregulated Flow

This study examined the interrelationships between numerous water withdrawals in the basin and the resulting impact on the timing, magnitude and frequency of regulated flow in the Saugus River. Annual Water Use reports were obtained from each registered and permitted water withdrawal in the basin[2] regulated by the Massachusetts Water Management Act for the period between 1994 and 1999. The monthly data for this 5-year period was displayed in various figures to understand the timing, magnitude and duration of withdrawals throughout the year.

The quantified water withdrawal data, in conjunction with flow data recorded at a United States Geological Survey (USGS) gage near the Saugus Ironworks, was used to estimate virgin or

[1] The Diversion Dam impounds water such that Lynn Water and Sewer Commission can divert water to Hawkes Pond, which is one LWSC's four water supply reservoirs.
[2] There are four registered withdrawals in the basin: Lynn Water and Sewer Commission, Lynnfield Center Water District, Sheraton Colonial Golf Course, Wakefield Water Department.

“natural” flow conditions in the Saugus River. Comparisons between the regulated and virgin flow conditions were conducted to understand how human activities affect streamflow. The findings indicate that the Saugus River flow is affected during low flow periods in the summer and during certain periods in the fall and spring, when water suppliers are attempting to refill their storage reservoirs. The Saugus River flow is not grossly affected during extremely high runoff periods, as the quantity of water withdrawn from the watershed is minimal compared to the magnitude of runoff.

LWSC’s large storage reservoirs offer operational flexibility for the timing of water withdrawals from the Saugus River; however, the slope and capacity of its diversion channel limits the rate and optimal management of its withdrawals.

Instream Flow Study to Determine Minimum Flows needed for Aquatic Habitat
In addition to estimating virgin flow conditions in the watershed, a habitat analysis was conducted for the purpose of developing minimum flow recommendations below the LWSC Diversion Dam[3]. Currently, LWSC is not required to maintain a continuous flow below the Diversion Dam and thus flow below the dam can be reduced to leakage. The lack of water below the Diversion Dam has an impact on the aquatic resources in this reach. An instream flow study (IFIM-instream flow incremental methodology) was conducted to quantify the relationship between flow and fish/macroinvertebrate habitat between the Diversion Dam and the USGS gage on the Saugus River (near the Saugus Ironworks in Saugus, MA)[4].

A detailed habitat map of the river was prepared from the Diversion Dam to the Saugus River USGS gage- a total of five river miles. The habitat mapping consisted of segmenting the Saugus River into habitat types of riffles, runs and pools. The breakdown of habitat types in the inventoried reach was as follows: 5.7% riffles, 93.0% runs, and 1.3% pools. The Saugus River is generally a slow moving stream comprised mostly of 1-2 foot deep runs with silt/sand substrates. There are limited riffle reaches, which are typically the most productive (in terms of food production for fish) habitat types.

Using the habitat maps, an instream flow study was conducted within two reaches of the Saugus River- one just below the LWSC Diversion Dam and the other downstream of Route 1 (referred to throughout the report as the Staples Reach). The upper reach near the LWSC Diversion has a relatively steep slope and consists of riffle/run sequences. In general velocities were high, depths low and the substrate was primarily sand, gravel and cobble. In contrast, the Staples Reach consists of slower moving riffles and runs and substrates were primarily sandy. These two reaches included the majority of riffles in the inventoried river. It is believed that if suitable aquatic habitat is maintained in the riffles, the remainder of the river will contain suitable habitat conditions.

Field data (flow, depth, velocity, substrate) was collected in these two reaches to develop hydraulic models. The hydraulic models were used to predict depth and velocities in each reach

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[3] The Diversion Dam is located in Wakefield below Reedy Meadows, a large wetland complex. The drainage area at the Diversion Dam is approximately 10.5 square miles. The Diversion Dam is the only dam on the Saugus River mainstem from the ocean to the base of Lake Quannapowitt.
[4] The USGS gage is located upstream of the Saugus River’s confluence with salt water.

over a range of flow conditions observed in the Saugus River. The hydraulic data was used in conjunction with fish preference curves (fish have certain preferences for depth, velocity and substrate) to estimate the quantity of fish habitat over a range of flows. A relationship between flow and fish habitat was developed for each of four species and life stage of fish plus macroinvertebrates were examined as part of this study. The flow yielding the most habitat for a given species and life stage of fish was quantified (alewife habitat was evaluated qualitatively since preference curves are not available for this species). Flows necessary to maintain at least 80% of the optimal habitat for all life stages of each target species were identified. The instream flow study was one tool used to estimate flow needs for aquatic resources below the LWSC Diversion Dam.

United States Fish and Wildlife Service- Aquatic Base Flow Policy
In addition to the habitat study, the natural flow yield of the Saugus River Basin was examined to determine if the flow needs resulting from the instream flow study could be supported from the natural flow in the basin. The natural flow at the Saugus River USGS gage and at the LWSC Diversion Dam was computed and compared against the United States Fish and Wildlife Services' (USFWS) Aquatic Base Flow Policy (ABF). Typically, the USFWS recommends that minimum flows be equivalent to the August median flow (during the summer), which is based on an unregulated river system. When no site-specific study is conducted or long-term record (25 years or greater) is available, the USFWS recommends a minimum flow equivalent to 0.50 cfs per square mile of drainage area. The estimated unregulated Saugus River flow at the gage is rather short (6 years)[5], however, recognizing the limited period of record, the Saugus River has a lower August median flow per square mile of drainage area (0.20 cfs per square mile of drainage area), when compared to the ABF Policy (0.50 cfs per square mile of drainage area).

Minimum Flow Recommendations at the LWSC Diversion Dam
Taking into account the physical landscape of the basin above the Diversion Dam, the natural hydrology of the watershed, the results of the instream flow study and the timing of the alewife run, shown in the table below is the recommended minimum flows for the LWSC Diversion Dam.

[5] It should be noted that this 6 year period was considered drier than the long-term average based on precipitation data.

Recommended Minimum Flows at the LWSC Diversion Dam

Period	Jun 1-Sep 30	Oct 1-Feb 28 (29)	Mar 1-Apr 30	May 1-31
Flow	3 cfs	6 cfs	12 cfs (see Note 3)	10 cfs (see Note 3)

Notes:
1. Minimum flows should be provided on a continuous basis
2. The minimum flows should be equivalent to total inflow to the Diversion Dam or the minimum flow listed in this table, whichever is less. For example, if total inflow to the Diversion Dam is 1 cfs in June, then the discharge at the Diversion Dam should be 1 cfs. If the total inflow to the Diversion Dam is 10 cfs in June, then the discharge at the Diversion Dam should be 3 cfs.
3. The original March 1-April 30 flow recommendation was set at 24 cfs, the approximate median monthly flow during these months. In addition, the original May flow recommendation was set at 6 cfs. However, LWSC was concerned that a 24 cfs release would impair their ability to refill their reservoirs for water supply needs. The recommendations reflect a compromise of water supply demands, and flow needs to restore and maintain the river herring run. As noted later in this document, it is highly recommended that the recommended spring minimum flows be implemented and that a formal river herring monitoring study be conducted over the next few years. Monitoring should be conducted to ensure that the recommended spring minimum flows are providing sufficient flow and particularly water depth to provide upstream passage needed to maintain and restore the Saugus River alewife/blueback herring run. Similarly, it is also highly recommended that an evaluation of the flow needs of outmigrating juvenile herring in the fall be conducted to ensure that there is sufficient depth to pass downstream (when the recommended minimum flow is 6 cfs). Although access to the headpond for spawning and juvenile development is not presently available because of the LWSC dam, if a fishway is provided in the future, maintenance of fall flows for juvenile outmigration will be necessary

In summary, the 3 cfs flow recommendation was based on the natural flow conditions in the basin, whereas the 6 cfs flow was based on the instream flow study. In addition, the 12 cfs and 10 cfs spring flows were based on maintaining a river herring run.

As stated earlier, the original March 1-April 30 flow recommendation was 24 cfs. This flow recommendation, which is the median unregulated flow for the combined months of March and April, was based on basin hydrology and not specific resource management objectives. The draft report also recognized that a minimum flow of 24 cfs would greatly impact LWSC's ability to withdraw water during a period when their reservoirs are being refilled.

Subsequent to issuance of the draft report there were further discussions regarding the flow recommendations and competing water uses. During the spring period those competing uses include: a) to restore and maintain a successful alewife run, b) maintaining LWSC's water supply diversions, and c) to recharge LWSC's reservoirs. To strike a balance between public water supply needs and environmental needs, the flow recommendations were revised to 12 cfs in March and April and 10 cfs in May.

To support the spring flow recommendations, it is recommended that a formal annual alewife monitoring/count program be implemented on the Saugus River after implementation of the spring minimum flow recommendations for monitoring purposes. In addition to counting alewives, flow data at the USGS gage at the Ironworks and releases from the Diversion Dam should also be recorded (flow and/or stage) to develop relationships between alewife counts and flow. Water temperature monitoring could also be conducted in an effort to establish a correlation with the timing of the herring run. Data for river herring runs in other nearby rivers could also be reviewed to compare the relative success of the recommended spring flows to re-establish the herring run compared to runs in other rivers. After a few years of data collection and analysis, further modification to the magnitude and timing of the spring minimum flows might be needed to ensure adequate upstream and downstream movement of adults. If river herring passage is successful the LWSC Diversion Dam is a barrier to further migration. The Corps is considering upstream passage at the Diversion Dam as explained further in Section 16.0 of this report.

In addition to the monitoring study of upstream migration, it is also recommended that a monitoring study of outmigrating juvenile alewives be conducted if a fishway is provided at the LWSC dam. Outmigration typically occurs in the fall, when the recommended minimum flow is 6 cfs. Similar to upstream passage, sufficient depth must be available for juveniles to migrate to the ocean. It may be necessary to restock alewife in the river to re-establish a run comparable in size to the historic populations. Restocking can be requested from the Massachusetts Division of Marine Fisheries once a fishway at the Diversion Dam is established.

On average, during the months of May, August, September and November, LWSC would have to curtail their withdrawals as summarized in table below.

Effect of Flow Recommendation on LWSC Water Withdrawals

Month	May	August	September	November	Total
Average Reduction in flow (cfs and MGD)	1.1 cfs (0.7 MGD)	1.7 cfs (1.1 MGD)	0.6 cfs (0.4 MGD)	2.4 cfs (1.5 MGD)	
Average Reduction in Volume of flow over the month (MG/month or MGM) (flow x no. of days per month)	21.8 MGM	34.7 MGM	11.2 MGM	46.1 MGM	113.9 MG

LWSC's average annual withdrawal from the Saugus River for the period 1994-1999 is 1,788 MG. Implementing the flow recommendations will reduce the LWSC's water withdrawal by 6.4% (113.9/1,788) on an annual basis and by 12%, 90%, 10%, and 18% during May, August, September and November, respectively (assuming withdrawals are not increased at other times of the year). During the remaining months, under average conditions, there is sufficient flow in the Saugus River to allow for increased water withdrawals by LWSC to offset the effects of the flow recommendations while still providing the recommended minimum flow.

It should be noted that implementation of these flow recommendations will only affect LWSC, although the inflow to the Diversion Dam is affected by other human activities. The Lynnfield Center Water District (LCWD) and Sheraton Golf Course withdraw water in the basin above the Diversion Dam. Lake Quannapowitt[6] is also operated to reduce lake levels in the fall and refill

[6] Lake Quannapowitt is also located above the Diversion Dam, at the head of the Saugus River Basin.

in the spring and there are other sources of regulation discussed in this report. These and other human activities affect the inflow to the Diversion Dam, and in some cases cause a reduction in inflow. Methods could be implemented where all water users above the Diversion Dam share in reducing withdrawals, in lieu of LWSC having to be solely impacted.

Water Quality
In addition to the instream flow study, water quality was also evaluated. Various agencies and volunteer groups have collected water quality data in the Saugus River Basin over the past several years. The river is considered a warm-water fishery due to high water temperatures, particularly during the summer period. Dissolved oxygen concentrations are below the Class B Warmwater Fishery standard of 5.0 mg/l at various locations in the basin- with most violations occurring in the summer period when water temperatures are high and flow is low. Most water temperatures are within the Class B standard of 28.3 °C, but are too high to be within the Class B coldwater standard of 20.0 °C. The Saugus River Watershed Council (SRWC) has been the major group collecting long-tem water quality data in the basin since 1992. Over the years, they have observed a progressive improvement in water quality. In 2001, LWSC established an informal agreement to maintain a continuous flow at the Diversion Dam. In collecting 2001 water quality data, the SRWC noticed improved water quality conditions- potentially as a result of maintaining a continuous flow. It is assumed that implementation of the minimum flow recommendations will only serve to further improve water quality.

Flood Issues
Flood conditions in the Saugus River Basin were evaluated at a cursory level. The Saugus River experiences flooding in the Reedy Meadows area as well as downstream near Route 1. Reedy Meadows is undergoing a natural eutrophication process, resulting in the meadow filling in over time and culverts becoming blocked. This has resulted in impeding flow movement through the meadows and increased flooding. It should be noted, however, that the Reedy Meadows and other nearby wetlands have also become filled in over time due to urban development thus reducing the flood retention of the wetland. A comparison of 1944 and 1987 topographic maps in this report shows that large tracts of wetlands have been filled. In general, increasing the water conveyance through Reedy Meadows by defining a clear channel and unclogging culverts could possibly reduce flooding around the meadows, but could exacerbate flooding downstream.

All impoundments or reservoirs in the Saugus River Basin were also evaluated to determine if the operation of these facilities could be modified to reduce flooding. The majority of reservoir storage in the basin is contained within LWSC's water supply system, which consists of four reservoirs (except for Lake Quannapowitt and other small impoundments). LWSC diverts water at the Diversion Dam via a canal to Hawkes Pond, where it is then distributed to three other reservoirs in LWSC's water supply network. The canal's flow carrying capacity is extremely limited, thus during a flood event the system provides minimal flood protection. All four water supply reservoirs also capture local runoff. Hawkes Pond has a tendency to fill and overflow back into the Saugus River during flood events and therefore is not often available for flood mitigation.

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Acronyms Conversions, and Definitions

Acronyms

C_d	Coefficient of Discharge
CF(I)	Compound Function Index
CDM	Camp, Dresser and McKee
cfs	cubic feet per second
cfsm	cubic feet per second per square mile of drainage area
CWF	Cold Water Fishery
DFWELE	Massachusetts Department of Fisheries, Wildlife and Environmental Law Enforcement
DO	Dissolved Oxygen
EPA	Environmental Protection Agency
EOEA	Executive Office of Environmental Affairs
GE	General Electric Company
GIS	Geographic Information System
gpcd	gallons per capita day
GS	Gomez and Sullivan Engineers, P.C.
FOLQ	Friends of Lake Quannapowitt
HSI	Habitat Suitability Index Curve (same as SI)
IFIM	Instream Flow Incremental Methodology
LCWD	Lynnfield Center Water District
LWSC	Lynn Water and Sewer Commission
MDFW	Massachusetts Division of Fisheries and Wildlife
MA-GIS	Massachusetts Geographic Information System
MDEM	Massachusetts Department of Environmental Management
MDEP	Massachusetts Department of Environmental Protection
MG	million gallons
MGD	million gallons per day
MGY	million gallons per year
mi^2	square miles
msl	mean sea level
MSWQS	Massachusetts Surface Water Quality Standards
MWRA	Massachusetts Water Resources Authority
NPDES	National Pollutant Discharge Elimination System
PHABSIM	Physical Habitat Simulation System
RESCO	Refuse Energy Systems Company
RBP	Rapid Bioassessment Protocols
S&I	Spawning and Incubation
SI	Suitability Index Curve (same as HSI)
SRWC	Saugus River Watershed Council
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
VAF	Velocity Adjustment Factor
WDPW	Wakefield Department of Public Works

WUA	Weighted Usable Area
WWD	Wakefield Water Department
WWF	Warm Water Fishery
WWTP	Wastewater Treatment Plant

Conversions

1 MGD=1.547 cfs
1 acre= 43,560 square feet
1 mi^2= 640 acres

Definitions:

Aquatic Macroinvertebrates- broadly defined as freshwater (aquatic) animals large enough to be seen by the naked eye (macro) and lacking a backbone (invertebrate)

Benthos- the community of benthic macroinvertebrates

HBI- the Hilsenhoff biotic index (HBI). This is an index of pollution tolerance for a given taxon.

Rapid Bioassessment Protocols- The protocols typically employ a kick-sampling method (less often rock baskets or multiplates) of collecting benthos, field assessment of habitat quality (to produce a habitat score), sorting to obtain a subsample of 100 organisms, calculation of indicator metrics and scores relative to a reference site. The result is categorization of the site as nonimpaired, moderately impaired, or severely impaired if taxonomy was performed to the family level (RBP II); or as nonimpaired, slightly impaired, moderately impaired, or severely impaired if taxonomy was performed to the genus/species level (RBP II).

1.0 Introduction

The Executive Office of Environmental Affairs Watershed Initiative North Coastal Basin Team commissioned a study to evaluate the relationship between streamflow regulation in the Saugus River and aquatic habitat needs. The Saugus River is a small coastal stream located north of Boston, MA that combines with the Pines River before emptying into the Atlantic Ocean. The freshwater portion of watershed is approximately 23.3 square miles and is highly regulated from a variety of sources.

The purpose of this study was to:

- Evaluate the Saugus River Watershed Characteristics including land use, surficial geology, topography, precipitation patterns (timing and magnitude). This evaluation was conducted to gain a better understanding of watershed physical characteristics and to quantify the magnitude and timing of precipitation totals in the watershed.

- Evaluate the registered water withdrawals in the Saugus River Watershed. There are four registered water users in the watershed. The study examined the magnitude and timing of water withdrawals over the past 6 years (1994-1999). One of the registered withdrawals, the Lynn Water and Sewer Commission (LWSC), operates a surface water withdrawal at a Diversion Dam located on the mainstem of the Saugus River. LWSC diverts water to a canal such that flows in the Saugus River, below the Diversion Dam, are sometimes reduced to leakage.

- An evaluation of the regulated and estimated unregulated (or natural) hydrology of the watershed was conducted. A United States Geological Survey (USGS) gage is located on the Saugus River near the Saugus Ironworks for the period March 1, 1994 to current. Using the regulated flows and the water withdrawal data, the natural flow regime at the USGS gage was estimated and compared against regulated conditions. The timing and magnitude of regulated and unregulated flow conditions were ultimately compared to determine the impacts caused by water withdrawals.

- A cursory evaluation of flooding in the basin was conducted. This included an evaluation of areas susceptible to flooding such as Reedy Meadows and near Route 1. In addition, the flood storage capacities of reservoirs in the basin were also examined to determine if the system could be operated to reduce flood levels.

- Historic water quality data was reviewed to put perspective on the general water quality conditions in the watershed—specifically water temperature, and dissolved oxygen. In general, the river is classified as a warm water fishery and water quality is considered fair to poor, although it has been improving over the years.

- A habitat map of the Saugus River from the LWSC Diversion Dam to the Saugus USGS Gage was developed to understand the habitat types and quality in the river. Habitat types were segmented by riffle, run and pools. The habitat mapping was later used in an instream flow study.

- The fish species expected to be present in the Saugus River were identified from historic reports, visual observation and from an ongoing habitat study on the nearby Ipswich River. The list of fish species was later used in an instream flow study.

- An instream flow study was conducted to quantify the relationship between flow and habitat for various species and life stages of fish (and macroinvertebrates) in the Saugus River. Hydraulic and habitat models were used to ultimately produce graphs depicting flow versus quantity of habitat for the various species and life stages analyzed.

- An evaluation of the natural watershed yield of the Saugus River was conducted. In general, the natural watershed yield of the Saugus River is low

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- A seasonal minimum flow recommendation was made to maintain continuous flows below the LWSC Diversion Dam. The goal of the flow recommendation is to improve fish habitat, riparian habitat, water quality and to ensure a continuous free-flowing river.

This study was conducted with active participation from several individuals and agencies, which helped shape the study. Gomez and Sullivan, authors of this report would like to thank the following individuals for their input on this important study:

- Dave Armstrong, United States Geological Survey,
- Phillips Brady, Massachusetts Division of Marine Fisheries
- Rick Dawe, Lynn Water and Sewer Commission,
- Cindy Delpapa, Massachusetts Department of Fisheries, Wildlife and Environmental Law Enforcement,
- Larry Gil, Massachusetts Department of Environmental Protection, North Coastal Team Leader, Executive Office of Environmental Affairs,
- Douglas Heath, Friends of Lake Quannapowitt
- Joan LeBlanc, Saugus River Watershed Council,
- Linda Marler, Massachusetts Department of Environmental Management,
- Janet Regan, National Park Service (Saugus Ironworks), and
- Todd Richards, Massachusetts Department of Fisheries, Wildlife and Environmental Law Enforcement.

The authors would also like to acknowledge Rick Dawe of the Lynn Water and Sewer Commission who was an active participant and of valuable assistance during this study. Rick arranged flow releases at the Diversion Dam to accommodate the instream flow study, provided an abundance of data that markedly improved the accuracy of the water budget calculations and provided survey assistance for portions of the study. The authors appreciate his and the entire teams effort on this comprehensive study.

It should be noted that several tables and figures are referenced in the document. If not presented within the text, tables and figures appear at the end of the section (tables first, then figures).

2.0 Saugus River Watershed

2.1 Watershed Description

The purpose of this section is to provide an overview of the Saugus River watershed characteristics (climate, geology, land use). The Saugus River is a coastal stream located north of Boston, MA as shown in Figure 2.1-1. The watershed includes portions of eleven Massachusetts's towns[7] and has a total drainage area of 47 mi^2. The above-tidal reach of the Saugus, terminating near the Saugus Ironworks (approximate location shown on Figure 2.1-1) has a drainage area of 23.3 mi^2, which represents 49% of the overall watershed. Below the Ironworks, additional drainage from several rivers enters the Saugus including the Pines River to the west, Shute Brook, Strawberry Brook/Little River and natural runoff. The 2,500-acre Town Line Brook watershed includes land in Revere, Malden, Melrose and Everett. The Town Line Brook, Linden Brook and portions of Rumney Marsh including the Sea Plane watershed are all part of the Town Line Brook watershed, which is located within the southern portions of the Saugus River watershed. This study focuses on the fresh water portion of the Saugus River; therefore, maps of the Saugus watershed include the mainstem of the Saugus River and its primary watershed. Most of the Town Line Brook sub-watershed is not shown because it is beyond the scope of this study.

The Massachusetts Executive Office of Environmental Affairs (EOEA) has established the Massachusetts Watershed Initiative, which assigns watershed team leaders to each of the major watersheds in Massachusetts. The Saugus River Basin is located within the North Coastal Basin along with several other small coastal streams such as the North River, Essex River, Annisquam River, etc.

Shown in Figure 2.1-2 is a topographic map of the Saugus River Basin. The maximum elevation of the basin, at approximately 267 feet mean sea level (msl), is located along the eastern rim of the basin, east of Breeds Pond. With the exception of a few hillsides, the majority of the watershed is below elevation 150 feet. Typically, steep-sided watersheds respond quickly to runoff events while mild sloped watersheds have a longer lag between precipitation and runoff. Although the Saugus River has mild slopes, urbanization and impervious surfaces result in greater and probably faster runoff volumes in the Saugus River Basin.

Shown in Figure 2.1-3 is the Saugus River profile, which was obtained from Camp, Dresser and McKee's (CDM) flood study. From Lake Quannapowitt, which forms the headwater of the watershed, to the tidal waters, the Saugus River drops approximately 83 feet over its 13-mile course. The overall river slope (0.0013) is characteristic of a slow-moving stream. A walk of the Saugus River from the Lynn Water and Sewer Commission (LWSC) Diversion Dam to the Saugus Ironworks confirms the sluggish nature of the river. Only in the upper and lower reaches does the river have any sizeable slope, as some riffles are evident just below the Diversion Dam, and just upstream of the Ironworks. Between these upper and lower reaches, the river is slow and relatively deep (1-3 feet).

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[7] Reading, Wakefield, Stoneham, Peabody, and Lynnfield are in the headwaters of the region. Portions of Melrose, Saugus, and Lynn are in the middle reaches of the river, above the estuarine reaches. Portions of Malden, Revere, Saugus, Everett and Lynn are in the estuarine reaches of the watershed.

2.2 Watershed Hydraulics and Sources of Regulation

Lake Quannapowitt, a 254-acre lake[8] in Wakefield, is located at the head of the watershed. The drainage area at the lake outlet is 750 acres (1.17 mi^2), thus the lake itself comprises one-third of its watershed area. Only one sizeable tributary (unnamed) enters the lake along the northwest shore. The tributary drains a series of wetlands along the southern border of Reading. A 7-foot-wide horizontal weir, located on the north shore, controls the lake outlet discharge (see Figure 2.2-1). Stoplogs are added or removed from the dam to raise or lower the lake level as needed.

A dam safety report (CDM, 1987) indicates that the normal operating procedure for Lake Quannapowitt consists of removing stoplogs (to lower the lake level) in the winter to provide additional storage in the event of high spring runoff. If high rates of runoff are experienced during spring, winter or fall, then stoplogs are added to the spillway to minimize flooding at susceptible areas downstream on the Mill and Saugus Rivers. In the summer, additional stoplogs are installed to raise the lake elevation to facilitate boating and other recreational activities. No long-term lake level data is available; however, since September 1999 data has been collected, periodically, by the Friends of Lake Quannapowitt (FOLQ). As shown in Figure 2.2-2, the lake is drawn down in the winter and refilled from the spring freshet. The difference between maximum and minimum elevation between September 1999 and March 2001 was approximately 1.62 feet.

Previous studies/reports do not provide any information on the lake elevation versus storage capacity of the lake. However, the dam safety report states that the storage volume at normal pool is estimated to be 2,200 acre-feet and at the top of dam, 2,500 acre-feet. It has also been reported that the lake is relatively shallow with a mean depth of 6.0 feet (Personal Communication, Doug Heath).

Discharges from Lake Quannapowitt pass through four culverts (Lowell Street, Vernon Street, Route 128 ramp and Route 128) before flowing into Reedy Meadows. Reedy Meadows is an expansive wetland that is fed by Beaverdam Brook to the north and discharges from Pillings Pond (99-acres)/Mill Pond (1-acre) to the east. In 1975, the U.S. Department of the Interior designated 540 acres of Reedy Meadows as a National Natural Landmark - (Ref: Cushing, 1996). Due to past flooding concerns around Reedy Meadows, various groups have studied flow conveyance through the meadows. These studies confirm that the channel system through Reedy Meadows has become restrictive to flow movement due to clogging of culverts through the B&M Railroad embankment, which bisects the meadow, and through clogging of the stream channels with sediments and vegetation (CDM, 1992).

Located within the Beaverdam Brook watershed in the northeast headwaters of the Saugus River are three water supply wells maintained by the Lynnfield Center Water District (LCWD). For purposes of discussion these wells are referred to as Station 1 (one well) and Station 3 (two wells). Note that two other individual wells (Stations 2 and 4) are located just to the north of Stations 1 and 3, however, they withdraw from the Ipswich River Watershed. The current

[8] The lake is about 11 feet deep generally in the area between Beebe Cove to the east and the Quannapowitt Yacht Club to the west.

registration allows LCWD to withdraw 0.32 MGD from the North Coastal Watershed (the Saugus Watershed is located in the North Coastal Watershed) and 0.29 MGD from the Ipswich River Watershed. More information is provided later in this document regarding LCWD withdrawals.

The artificially created Pillings Pond (99 acres) has historically been lowered approximately 1-2 feet (Personal Communication, Joe Maney, Lynnfield Town Manager) in the fall and refilled in the spring. Dredging of the pond was started by the Town, but halted by the Army Corps of Engineers (ACOE) in August 1996. A gate at the outlet regulates pond discharges. Since January 1998, the town has managed the lake at a constant elevation. Discharges from Pillings Pond flow under Summer Street and into Mill Pond (1-acre), which is privately owned. An outlet structure is also located at Mill Pond (currently undergoing remediation), which regulates releases into Reedy Meadows.

The Saugus Diversion Dam, owned by LWSC, impounds Reedy Meadows near the Colonial Sheraton Country Club. The drainage area at the Diversion Dam is approximately 10.5 mi^2. The Diversion Dam is 20-feet wide and approximately 7-feet high from the spillway crest to the downstream apron. Integral to the dam is a 6-foot x 6-foot sluice gate (referred to as dam gate hereafter), which is operated by LWSC. Discharges from the gate and spillway regulate the flow in the Saugus River. Along the east side of the Reedy Meadows headpond, approximately 600 feet east of the Diversion Dam, is a 4-foot x 6-foot sluice gate located in the LWSC diversion canal (referred to as canal gate hereafter). Flow through the sluice gate travels along a canal and eventually into Hawkes Pond, which is part of the LWSC water supply reservoir system. The dam and diversion system were constructed circa 1893. A plan view of the Diversion Dam and canal gates is shown in Figure 2.2-3. In addition, shown in Figure 2.2-4 are photographs of the Diversion Dam and canal gate. Depending on the time of year and demand for water there are instances where no water is passed below the Diversion Dam (except for leakage), while water is flowing through the canal. There are also instances when flow moves backwards in the canal, if the water level in Hawkes Pond higher than the Reedy Meadows head pond. Under these conditions, LWSC opens both the canal and dam gate to allow water to pass down the Saugus River.

Because LWSC controls the discharges at the Diversion Dam and canal gates, they also control the water levels near the Reedy Meadows outlet. LWSC has indicated that the control of Reedy Meadows water levels is limited to the water bodies in the meadow located immediately upstream and abutting the dam due to influence by the natural and manmade obstructions located upstream. Due to hydraulic restrictions, water levels further upstream in the meadows are not immediately impacted by water level changes at the Diversion Dam.

LWSC records Reedy Meadow headpond elevations as well as canal elevations on a daily basis based on measure downs from separate reference points, which were recently tied together by survey. These data are examined in Section 3.0 to characterize the water level regulation occurring near the outlet of Reedy Meadows.

LWSC is registered to withdraw from the Saugus River an average of 8.93 MGD throughout the year. Located near the LWSC withdrawal is the Colonial Sheraton Country Club. The golf course is also registered to withdraw up to 0.20 MGD from an unnamed pond. More information is provided later in this document regarding Colonial Sheraton water withdrawals.

Below the Diversion Dam the Saugus River flows southerly through a culvert under Route 128 and a natural channel under Salem Street. Below Salem Street an unnamed tributary drains along the eastern portion of the watershed near Montrose Avenue. The river then passes under Route 129, where the Mill River empties into the Saugus River. Feeding into the Mill River is overflow discharge from Crystal Lake, a water supply source for the Wakefield Water Department (WWD). The WWD has a registered withdrawal from Crystal Lake of 0.48 MGD. Similar to the other registered users, more information is provided later in this document regarding the WWD withdrawals.

The Saugus River flows easterly, until it reaches Cedar Glen Country Club on Water Street, where it then redirects southerly before Hawkes Brook enters. Hawkes Brook originates from wetlands upstream and west of Hawkes Pond. Flow in Hawkes Brook consists of natural runoff plus discharge from Walden Pond when the spillway is overtopped. Walden Pond spillage connects to Hawkes Brook at Spring Street in Saugus, below Hawkes Pond Dam.

After flowing through Breakheart Reservation, the river flows under Route 1, Central Street and Elm Street in the town of Saugus. Near Route 1, Crystal Pond Brook enters the Saugus River from the west. The freshwater portion of the drainage terminates near the Saugus Ironworks. The Saugus Ironworks is a National Park Service site and location of a historical ironworks. Below the Saugus Ironworks, the Shute River enters from the west. Below the Shute River confluence, and prior to its discharge into the ocean, the Saugus River converges with the Pines River- this area has been designated by the Commonwealth as an Area of Critical Environmental Concern. Rumney Marsh, a 600+ acre reservation, is located within the rich Saugus and Pines River estuary. This expansive saltmarsh provides habitat for an array of wildlife including migratory birds and marine life.

Additional details regarding the mainstem Saugus River channel and its pathway are presented in Section 8.0 and Appendix H.

2.3 Surficial Geology

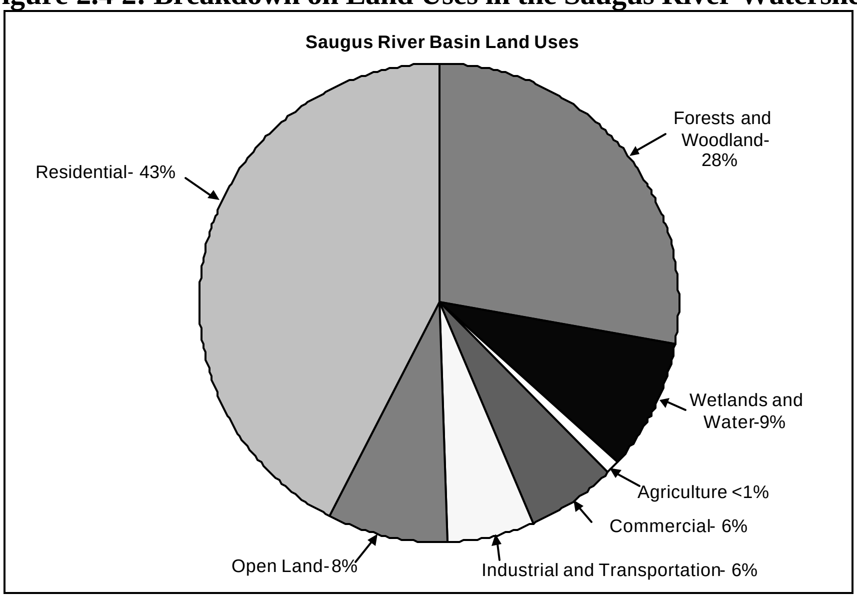
The Mass-GIS was contacted to obtain surficial geology mapping of the Saugus River Watershed as shown in Figure 2.3-1. The Saugus River Watershed is located within the Boston Lowland Division of the Boston Watershed, and underlain by volcanic and metamorphic rocks of Paleozoic age. Bedrock outcroppings are especially evident in portions of Saugus and Lynn, near the eastern rim of the watershed.

The last glaciation of the area occurred approximately 10,000 years ago during the Pleistocene. This glacial activity formed the watershed's current morphological characteristics. Based on surficial geology, the Saugus River Watershed can be separated into two distinct areas. The lowermost portion of the watershed is characterized by surficial formations of floodplain alluvium and fine-grained deposits, with some areas of sand and gravel deposits. This portion of the watershed is under tidal influence and is comprised of salt marshes, tidal flats, and other low-lying areas. The remaining portion of the watershed has variable topography with maximum elevations of approximately 267 feet mean sea level (msl); however, the majority of the watershed is below elevation 150 feet. Deposits of glacial till or bedrock outcroppings in higher elevation areas characterize most of this portion of the watershed. Sand and gravel deposits, as well as smaller deposits of floodplain alluvium are evident in valley areas.

2.4 Land Use

The Mass-GIS also provided land use data of the Saugus River Basin as shown in Figure 2.4-1. The watershed and Saugus River corridor are comprised primarily of residential, urban, and commercial uses. In addition, there are several major transportation corridors that parallel or cross the Saugus River. However, there are significant contiguous areas of forested land within the watershed. These areas are located east of Lake Quannapowitt, along a reach of the Saugus River below the Diversion Dam and above the town of Saugus, and the Hawkes Pond, Walden Pond, and Birch Pond locale. Shown in Figure 2.4-2 is the approximate break down of land uses in the watershed. Interestingly, the amount of forest land represents 28% of the watershed area, with the majority of this area being located near the LWSC storage reservoirs.

Figure 2.4-2: Breakdown on Land Uses in the Saugus River Watershed



2.5 Climate

The Saugus River Watershed is located on the north coast of Boston at 42 22' Latitude, 71 02' Longitude. It is important to have an understanding of the total and seasonal precipitation within the Saugus River Watershed as it has a direct influence on the timing and magnitude of runoff. A long-term precipitation gage is located in Lynn, at the water treatment plant in the northern portion of the Saugus River Watershed. The Lynn gage, maintained by LWSC, has a period of record from 1874-present. There is also a long-term precipitation gage located in Wakefield, with a period of record from 1937 to current.

General statistics for both precipitation gages are summarized Table 2.5-1.

Table 2.5-1: Precipitation Statistics at the Lynn and Wakefield Gages

Statistic	Lynn Precipitation Gage (1874-current)	Wakefield Precipitation Gage (1937-current)
Average Annual Precipitation	41.9 inches/year	40.5 inches/year
Maximum Annual Precipitation	61.56 inches in 1996	59.66 inches in 1998*
Minimum Annual Precipitation	24.41 inches in 1964	25.47 inches in 1995
Average Monthly Minimum Precipitation	3.11 inches in June	2.98 inches in July
Average Monthly Maximum Precipitation	3.84 inches in November	4.07 inches in November
Maximum Monthly Precipitation	14.87 in August 1955	14.95 inches in June 1998
Minimum Monthly Precipitation	0.01 inches in June 1999	0.00 inches in June 1999

* Note that the gage did not operate during all of 1996 (another wet year)

As shown in Figures 2.5-1 and 2.5-2, precipitation patterns over the year are relatively stable at the Lynn and Wakefield gages, respectively. The average monthly precipitation over the period of record does not vary considerably at both gages- see Table 2.5-1. Average monthly precipitation ranges between 3 and 4 inches. Precipitation for the period that the USGS gage at Saugus Ironworks has been recording Saugus River flow (March 1994 through June 2000) has in general been more variable than the long-term historic precipitation pattern. The average monthly precipitation ranged from 2.51 inches (July) to 5.54 inches (October). Therefore, the USGS gage flow data reflects a greater range of conditions than the historic averages. In general, the close proximity of the ocean results in a moderation of the climate. However, the watershed is subject to heavy rainfall and wind from Atlantic coastal storms. Storm tides and wave action can produce flooding in lowland coastal areas. Snowpack development over the winter months and resultant spring snowmelt can also elevate flow during spring months (typically March and April).

Daily precipitation records at the Lynn gage were also reviewed to identify any high precipitation events of interest and the resultant recorded river flow. On October 20, 1996, the Lynn gage recorded 9.54 inches of precipitation (the total precipitation for this month was 13.82 inches, which is the highest monthly total on record while the USGS gage was operating). On October 21, 1996, the Saugus River average daily flow, as recorded at the USGS gage at the Saugus Ironworks was 812 cfs, which is the highest flow on record since the gage was installed on March 1, 1994.

Low precipitation periods at the Lynn gage were also examined, although the correlation between precipitation and flow is not direct due to regulation. The prolonged drought of the mid 1960’s, experienced throughout the Northeast, resulted in the lowest annual precipitation on record. Precipitation totals for 1964, 65 and 66 were 33.58, 24.41, and 33.39 inches, respectively, well below the average. More recent low flow precipitation events occurred in August 1995 and June-September 1997. The total precipitation for August 1995 was 1 inch (average 3.54 inches), while the average monthly flow, as recorded at the Saugus USGS gage, was 1.8 cfs. June-September 1997 precipitation totals were 0.9, 1.08, 3.15, and 1.49 inches, respectively (total of 6.62 inches as compared to the average of 13.16 inches). The summer of 1997 was the third driest summer on record with respect to precipitation behind 1957 (4.44 inches) and 1950 (6.20 inches). The corresponding average monthly flows at the USGS gage during June-September 1997 were 5.8, 2.23, 3.14, and 2.11 cfs, respectively.

Air temperature also impacts Saugus River water temperatures and water quality. The wide expansive surface water areas of the watershed, most notably Lake Quannapowitt and Reedy Meadows, are subject to direct sunlight, solar radiation and increased water temperatures as air temperatures rise. Air temperature is recorded in the lower Saugus River Basin (near the coast) by a weather observer; however, the data is only available in paper copy format (Personal Communication, David Taylor, Weather Services Corp). Given the time needed to keypunch the data, and given that the observer station is near the coast, it was decided to use electronic formatted air temperature data recorded at Boston since it has a long-term period of record (and is also coastal). The air temperatures recorded in Boston (near Logan airport) may vary somewhat from the air temperatures experienced in the inland portion of the Saugus Basin. However, the data adequately characterizes the seasonal variability in air temperatures throughout the year. Shown in Figure 2.5-3 are monthly average temperatures (minimum, average, and maximum) for Boston based on a period of record from 1872 to present. The average annual air temperature is approximately 50.6°F. Lowest temperatures occur in January (average 28.9°F) and highest temperatures occur in July (average 72.8°F).

2.6 Historic Industrial Use of the Saugus River

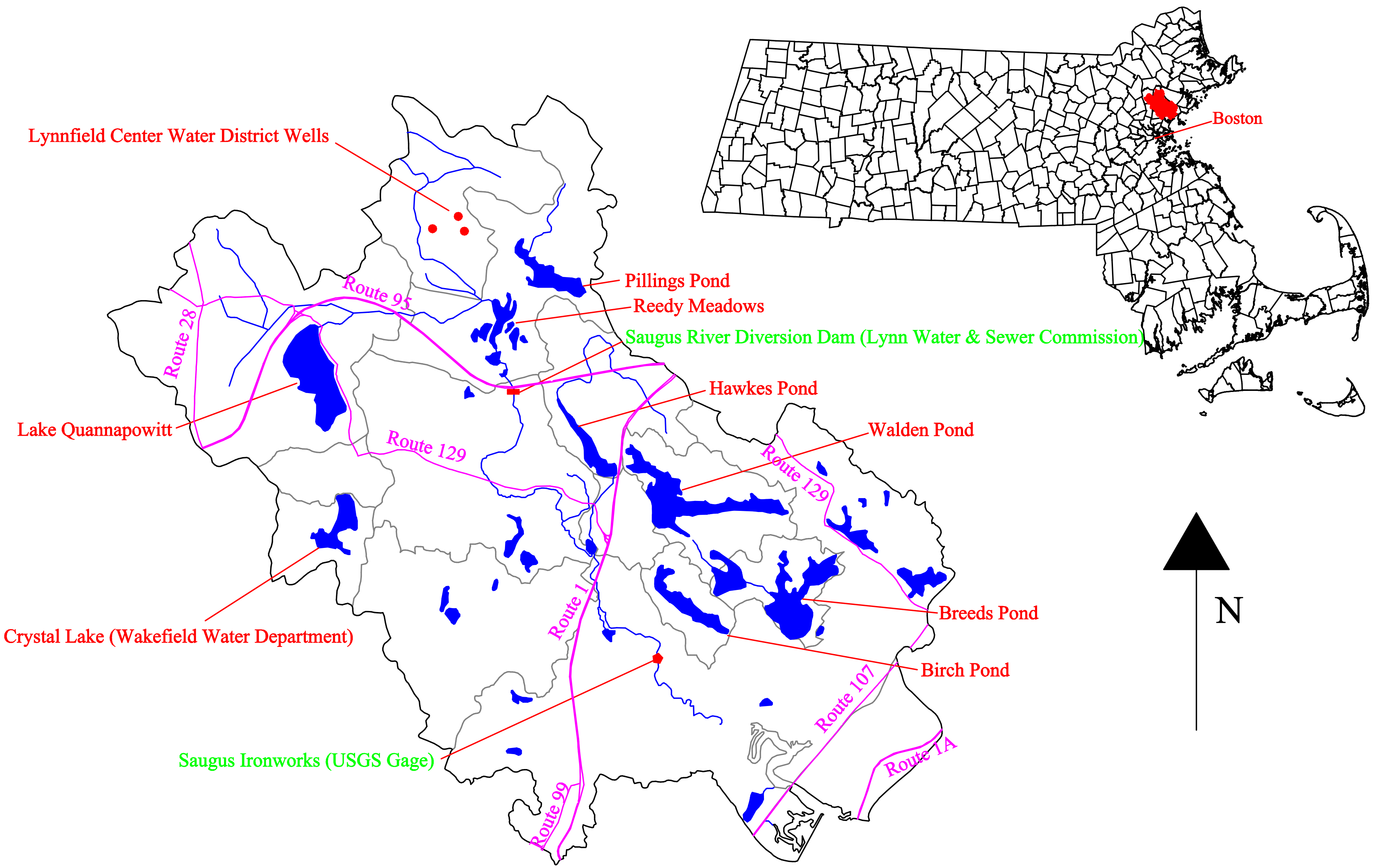
Janet Regan of the National Park Service provided some history on the industrial use of the Saugus River as summarized below.

The Saugus River is one of the first American rivers to be harnessed for industrial purposes. Historic records indicate that a gristmill may have operated on the river in the 1630's. Extensive manipulations of the river for heavy industry began in 1646 with the construction of a large-scale iron works. Since the time of the colonial iron works, the Saugus River has been subject to continuous industrial use.

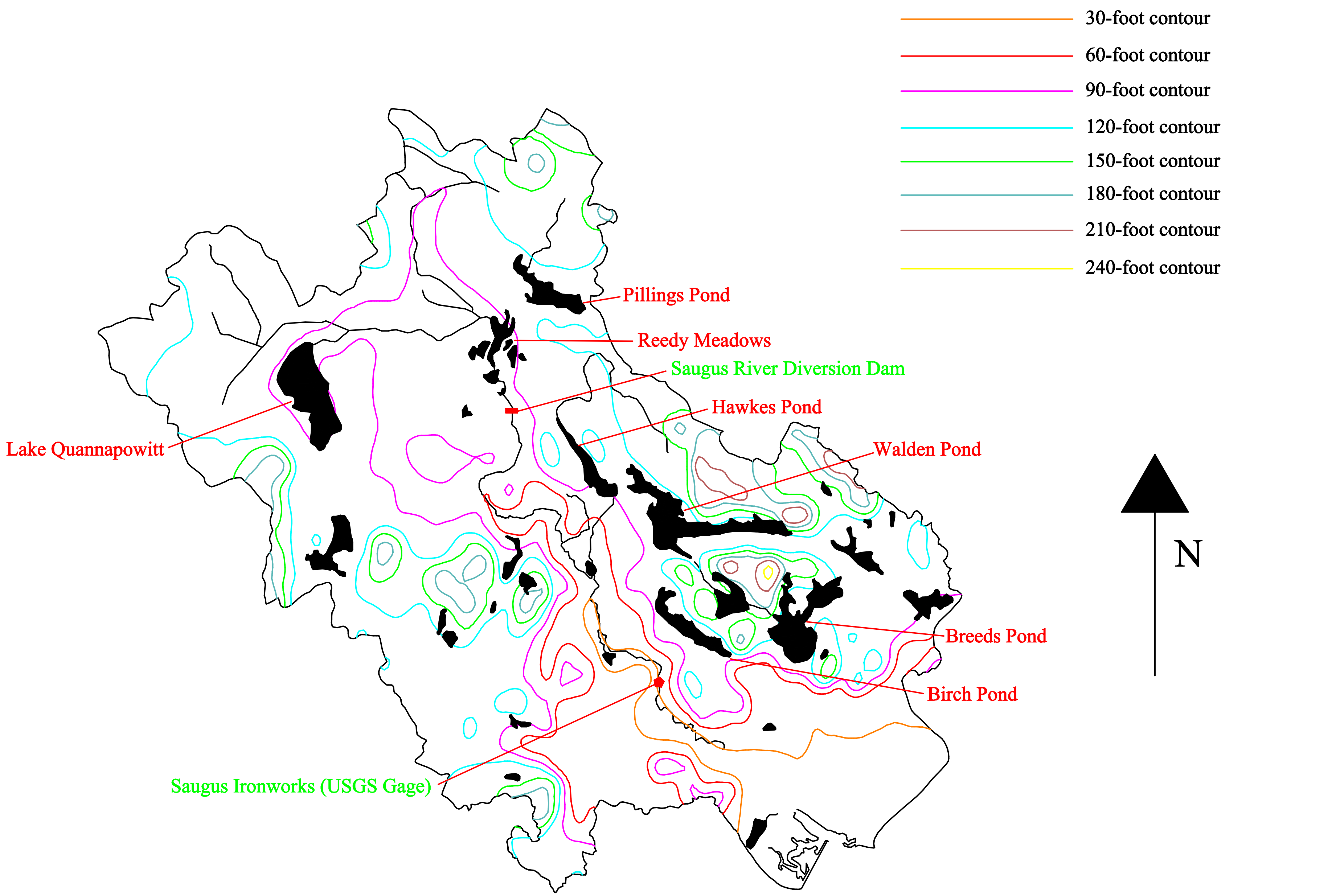
In the seventeenth, eighteenth, and nineteenth centuries, dams provided waterpower to factories along the river, using both freshwater and tidal flow. Its clay was used for brick making. The tidal portion of the river was used as a transportation corridor. Early factories included saw-mills, grist mills, a second iron works, and various textile factories (wool processing, duck cloth manufacturing, bleaching and calico printing, flannel manufacture, linen spinning and dye making). Other early enterprises were leather treating mills, shoe factories, a wire and screw plan, ship building, whaling and fishing wharves, and cigar, snuff, spice, coffee, and chocolate mills.

The twentieth century, no longer reliant on waterpower, saw enterprises such as furniture making, photographic tinting, a tidal power plant, carburetor and gasoline engine production, textile processing, leather treating, and fish oil manufacture. Additional twentieth century businesses included ice production, boat yards, and clam harvesting. The river is still home to a large lobster fleet. Today the Refuse Energy Systems Company (RESCO) and General Electric plants are the largest industries in use along the Saugus River.

Janet Regan provided an approximate Saugus River Basin map reflective of the year 1867 as shown in Figure 2.6-1. In addition, shown in Figure 2.6-2 is a map of Saugus from 1872.



Saugus River Basin Map
Approximate Scale 1=100,000
FIGURE 2.1-1



Saugus River Basin-Topography
Approximate Scale 1=100,000
FIGURE 2.1-2

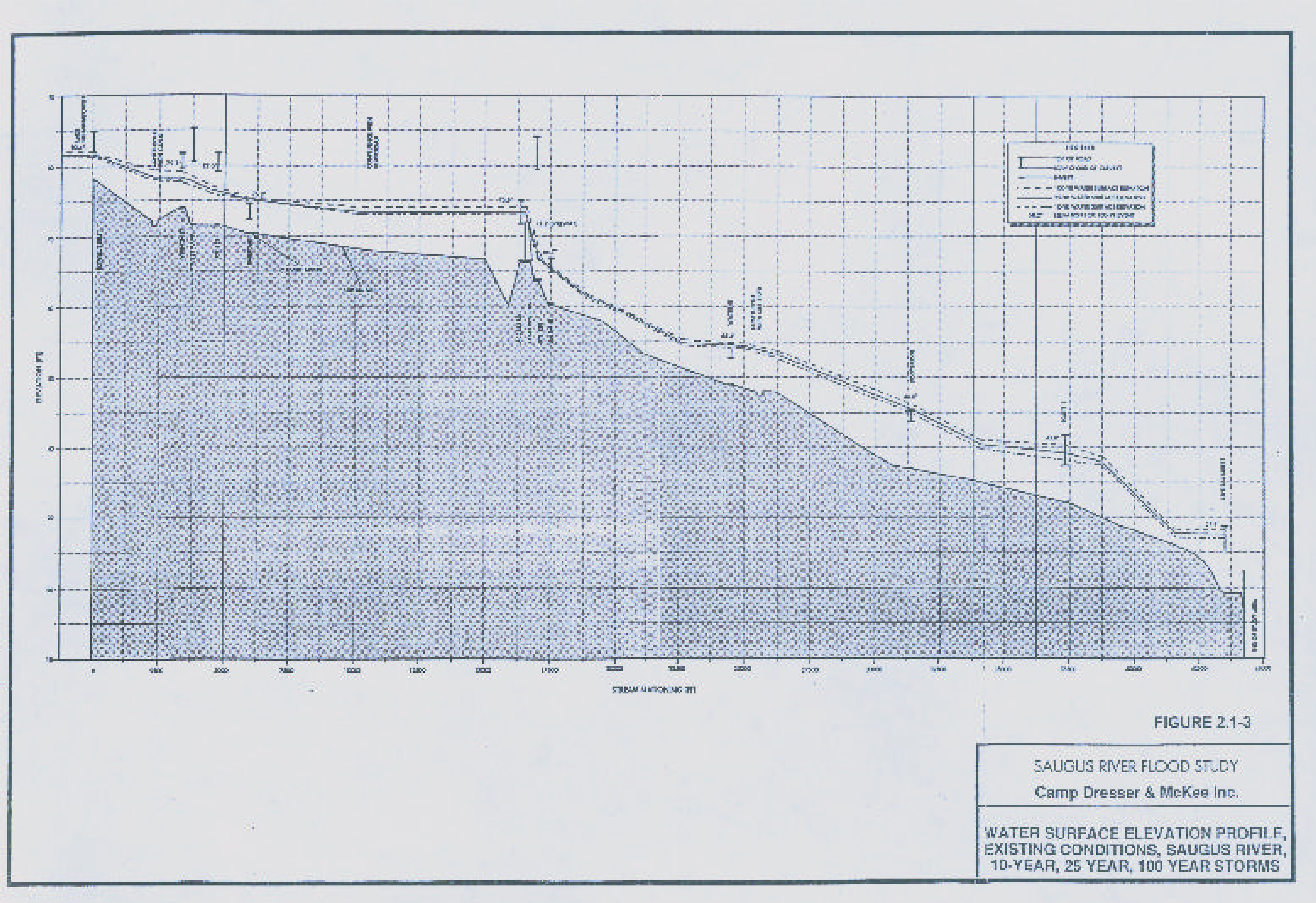


FIGURE 2.1-3: Saugus River Profile

Lake Quannapowitt Outlet, Looking at Outlet

Outlet width is approximately 7 feet. Boards are added or removed from slots to raise or lower the lake level accordingly.

Looking at Lake Quannapowitt from Outlet

Photos of Lake Quannapowitt Outlet   FIGURE 2.2-1

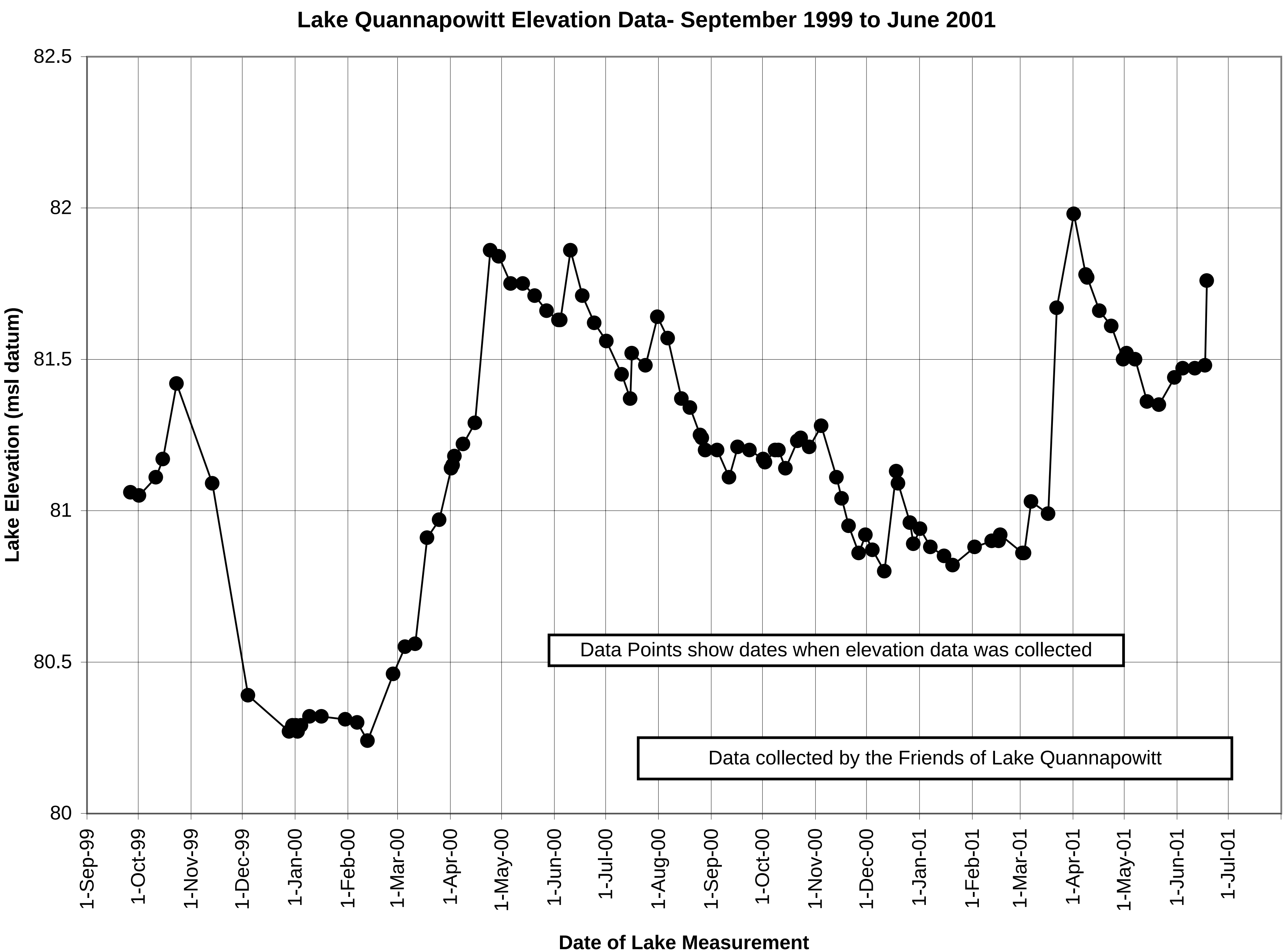
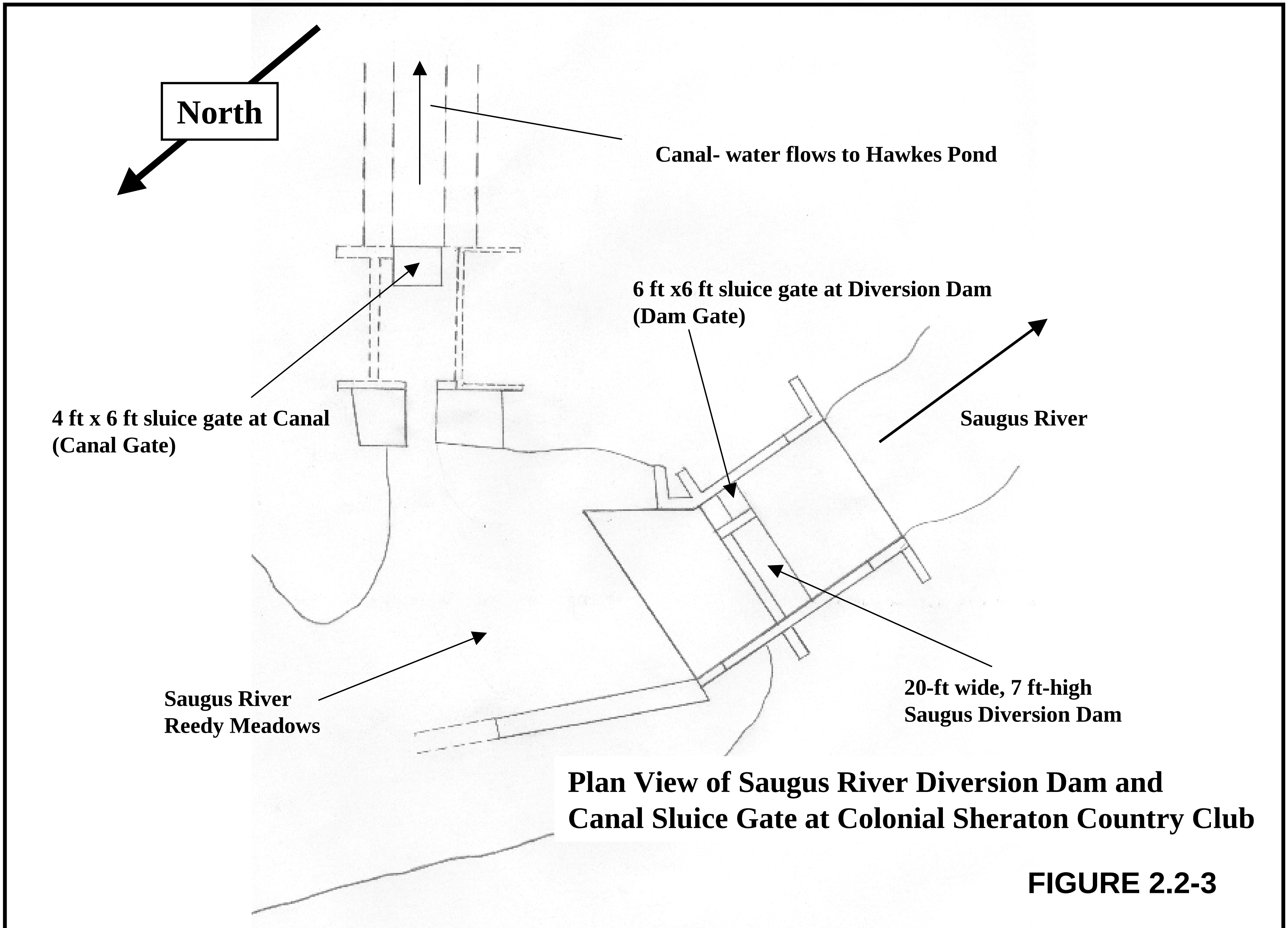

Lake Quannapowitt Elevation Data- September 1999 to June 2001
Lake Elevation (msl datum)
82.5
82
81.5
81
80.5
80
Data Points show dates when elevation data was collected
Data collected by the Friends of Lake Quannapowitt
1-Sep-99
1-Oct-99
1-Nov-99
1-Dec-99
1-Jan-00
1-Feb-00
1-Mar-00
1-Apr-00
1-May-00
1-Jun-00
1-Jul-00
1-Aug-00
1-Sep-00
1-Oct-00
1-Nov-00
1-Dec-00
1-Jan-01
1-Feb-01
1-Mar-01
1-Apr-01
1-May-01
1-Jun-01
1-Jul-01
Date of Lake Measurement

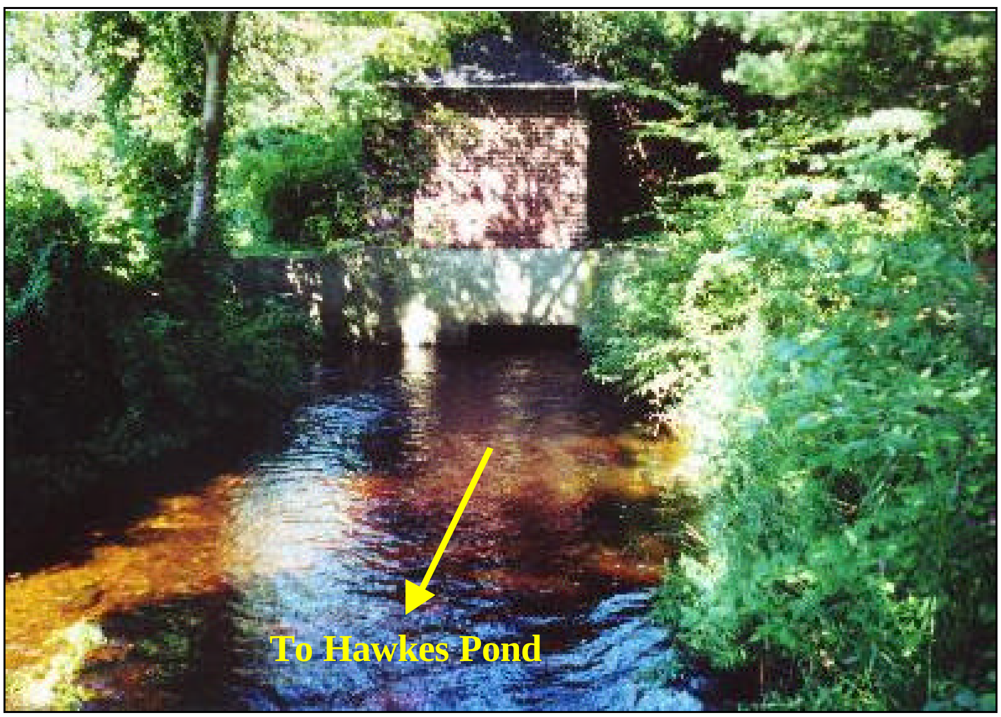
FIGURE 2.2-2



Plan View of Saugus River Diversion Dam and Canal Sluice Gate at Colonial Sheraton Country Club

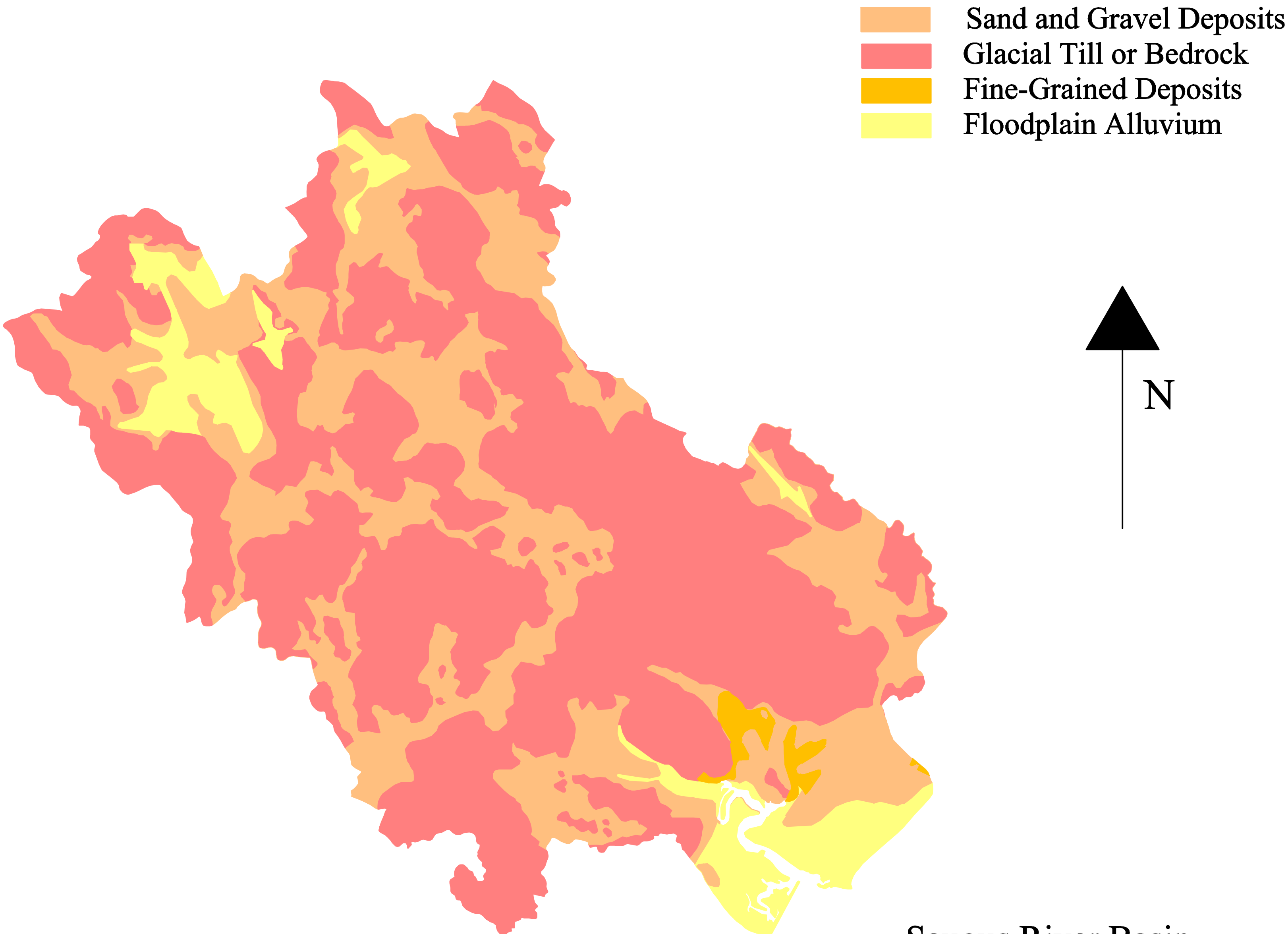
FIGURE 2.2-3

Looking Upstream at Diversion Dam (on left) and Sluice Gate (on right)

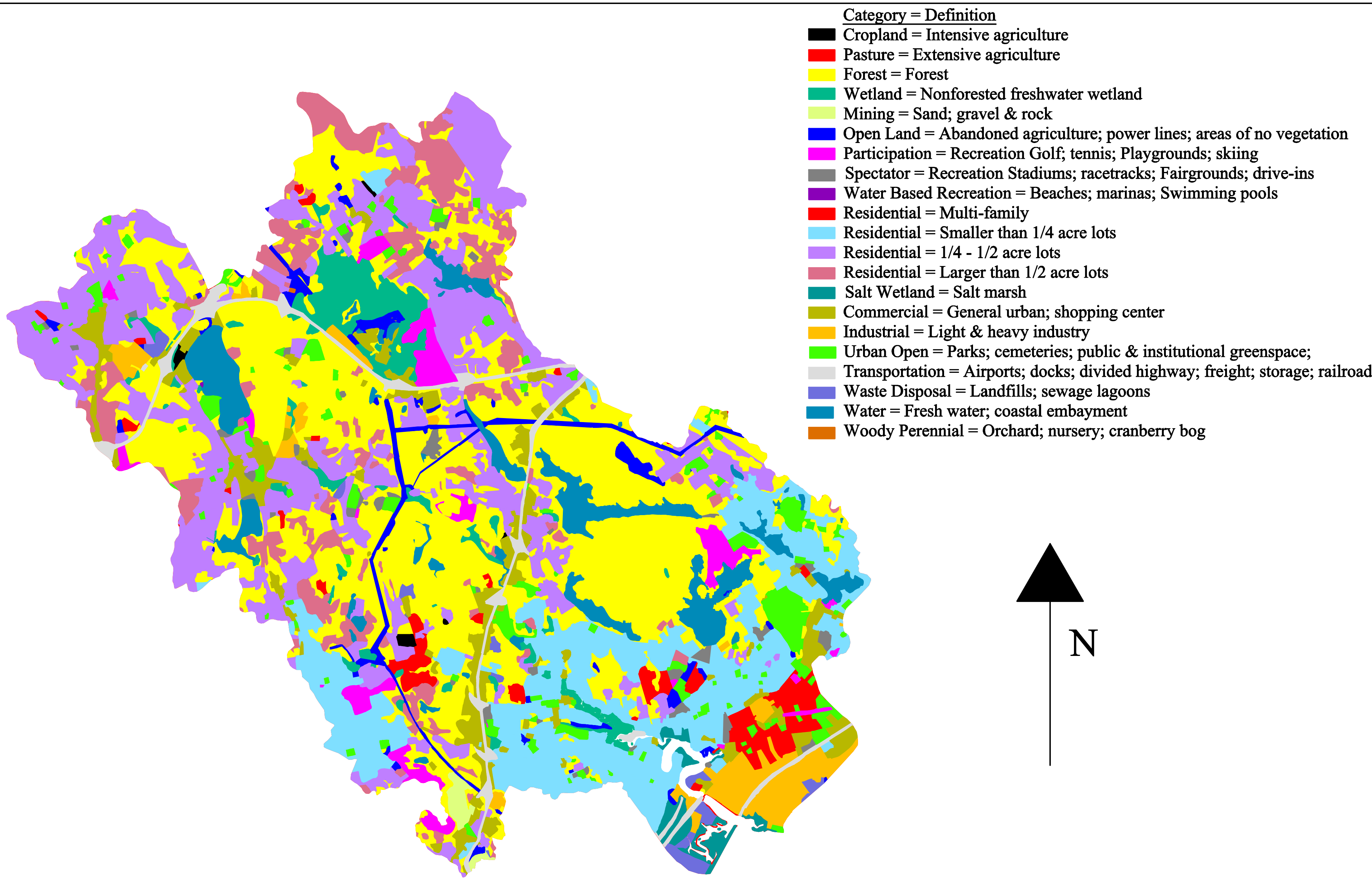


Looking upstream at Canal Sluice Gate

Photographs of Diversion Dam and Canal Sluice Gate   FIGURE 2.2-4

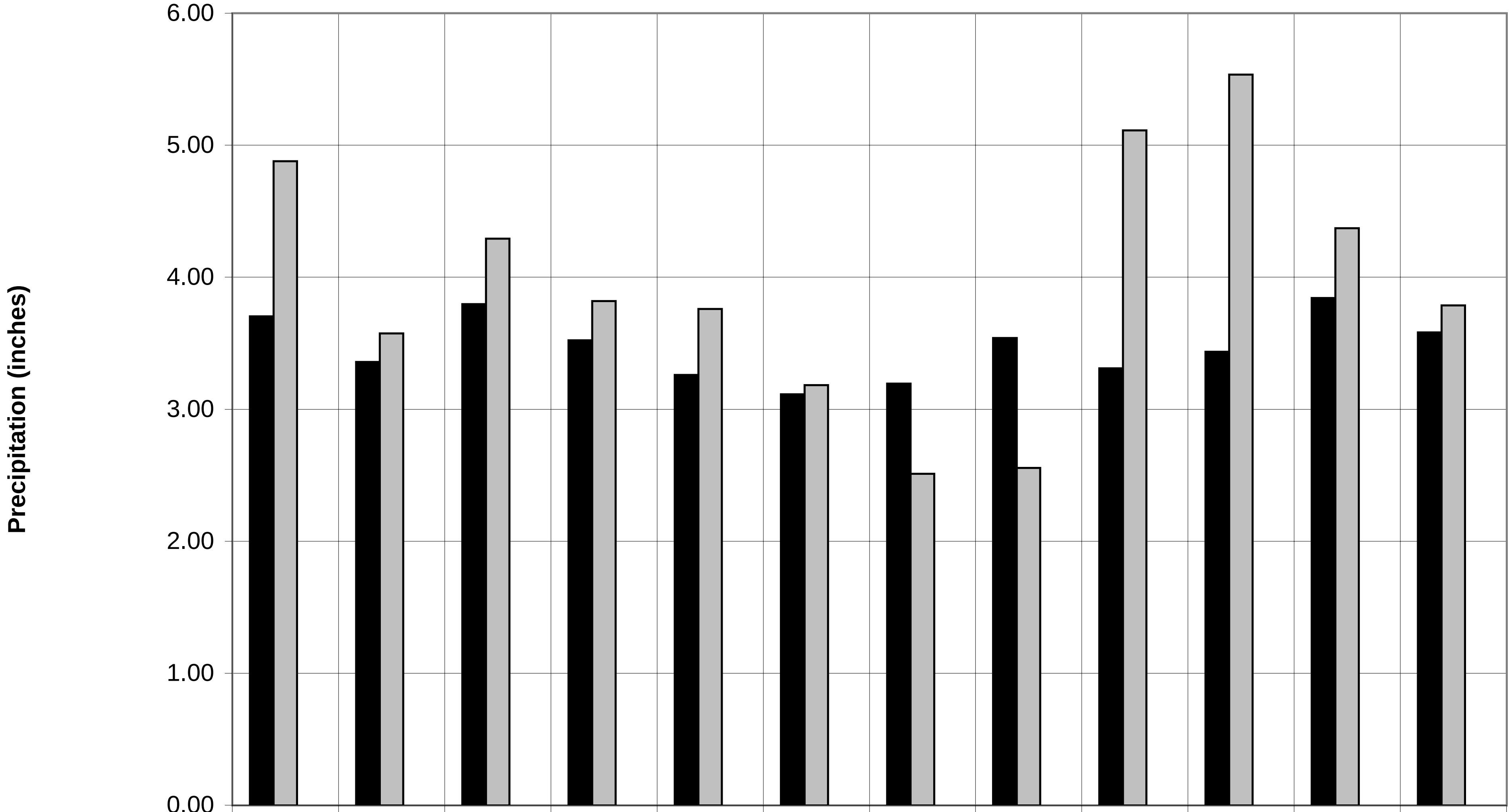


Saugus River Basin
Surficial Geology
Approximate Scale 1 = 100,000
FIGURE 2.3-1



Saugus River Basin
Land Use
Approximate Scale 1=100,000
FIGURE 2.4-1

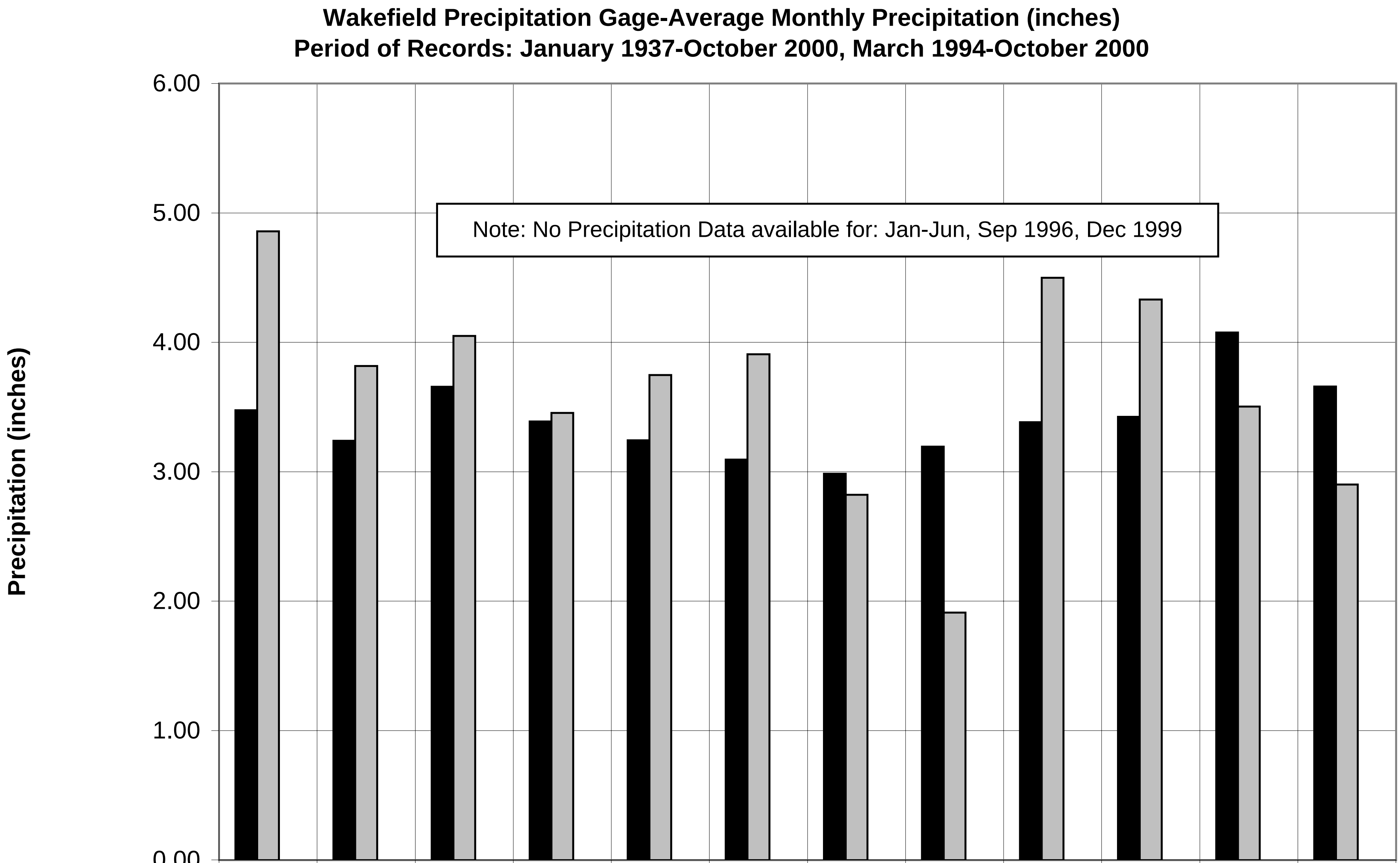
Lynn Precipitation Gage- Average Monthly Precipitation (inches)
Period of Records: July 1872-June 2000, March 1994-June 2000



	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
■ 7/1872-6/2000	3.70	3.36	3.80	3.52	3.26	3.11	3.19	3.54	3.31	3.44	3.84	3.58
□ 3/1994-6/2000	4.88	3.57	4.29	3.82	3.76	3.18	2.51	2.56	5.11	5.54	4.37	3.79
Percent Difference	31.7%	6.4%	13.1%	8.4%	15.3%	2.2%	-21.4%	-27.8%	54.4%	61.1%	13.8%	5.7%

Month

FIGURE 2.5-1



	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
■ 1/1937-10/2000	3.48	3.24	3.66	3.39	3.24	3.09	2.98	3.19	3.38	3.42	4.07	3.66
□ 3/1994-10/2000	4.86	3.82	4.05	3.46	3.75	3.91	2.82	1.91	4.50	4.33	3.50	2.90
Percent Difference	39.8%	17.8%	10.7%	2.0%	15.5%	26.3%	-5.4%	-40.2%	33.0%	26.5%	-14.0%	-20.7%

Month

FIGURE 2.5-2

Boston, MA Weather Station, Monthly Average, Minimum, and Maximum Temperature Data, Period of Record: March 1872-March 2000

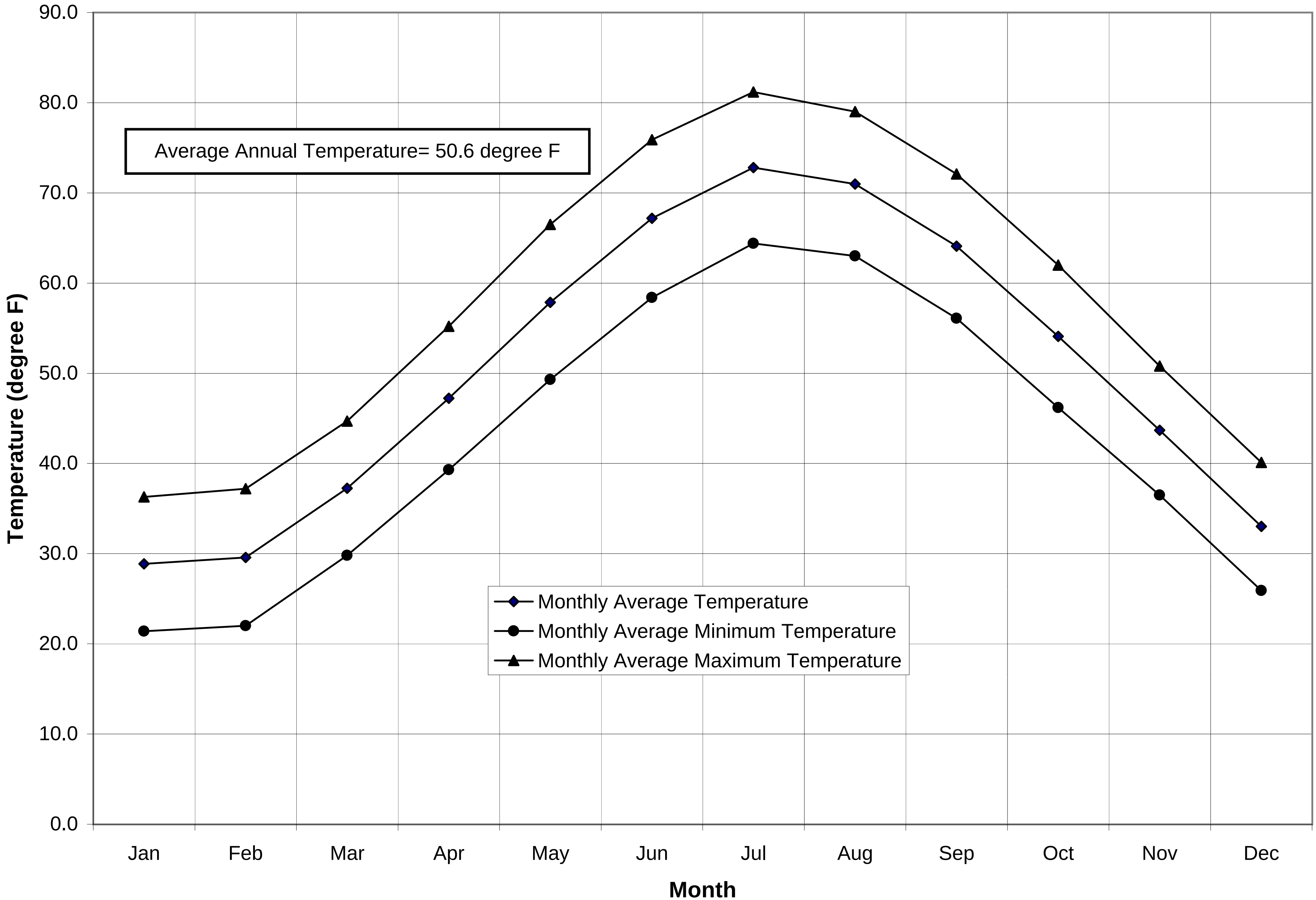
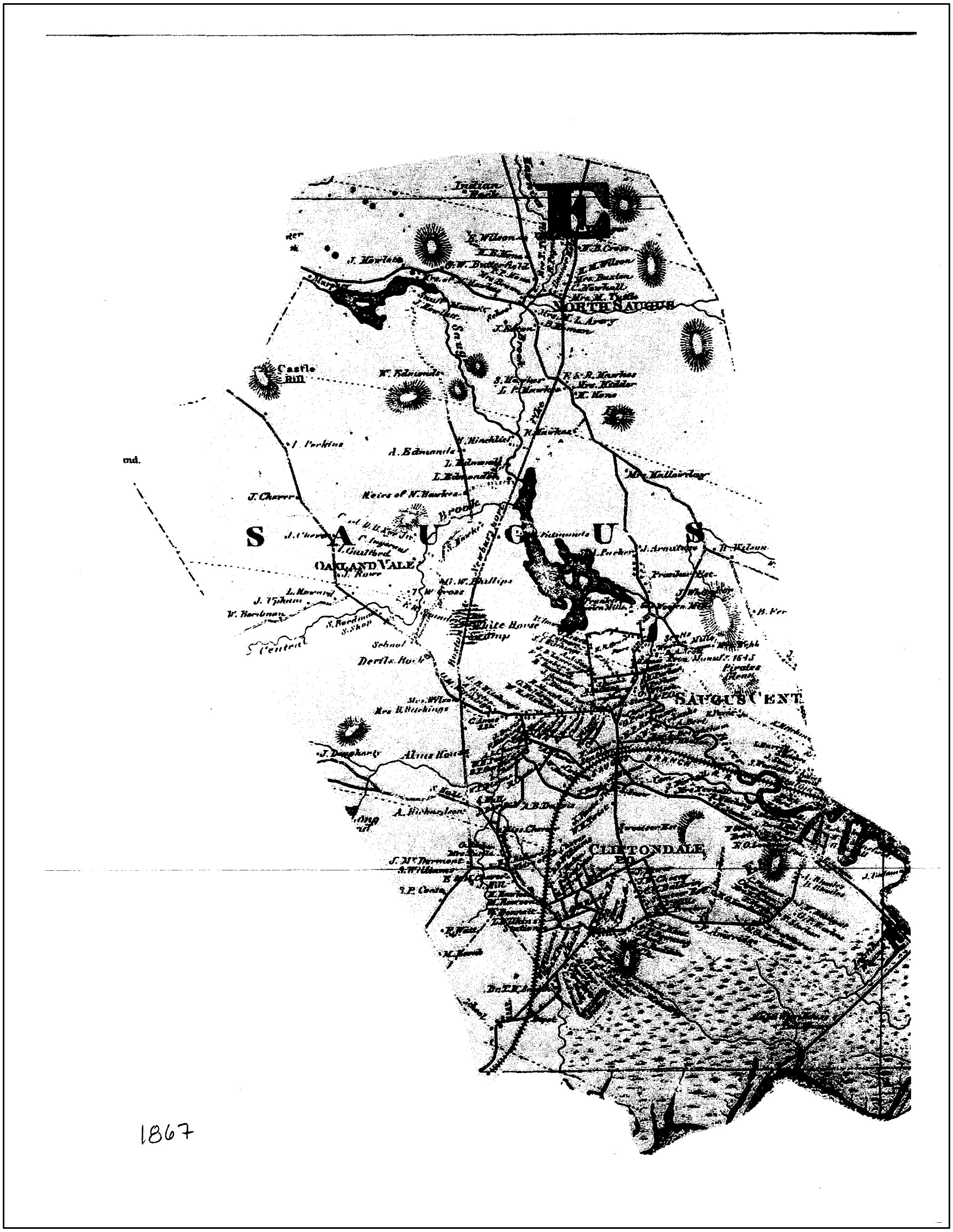
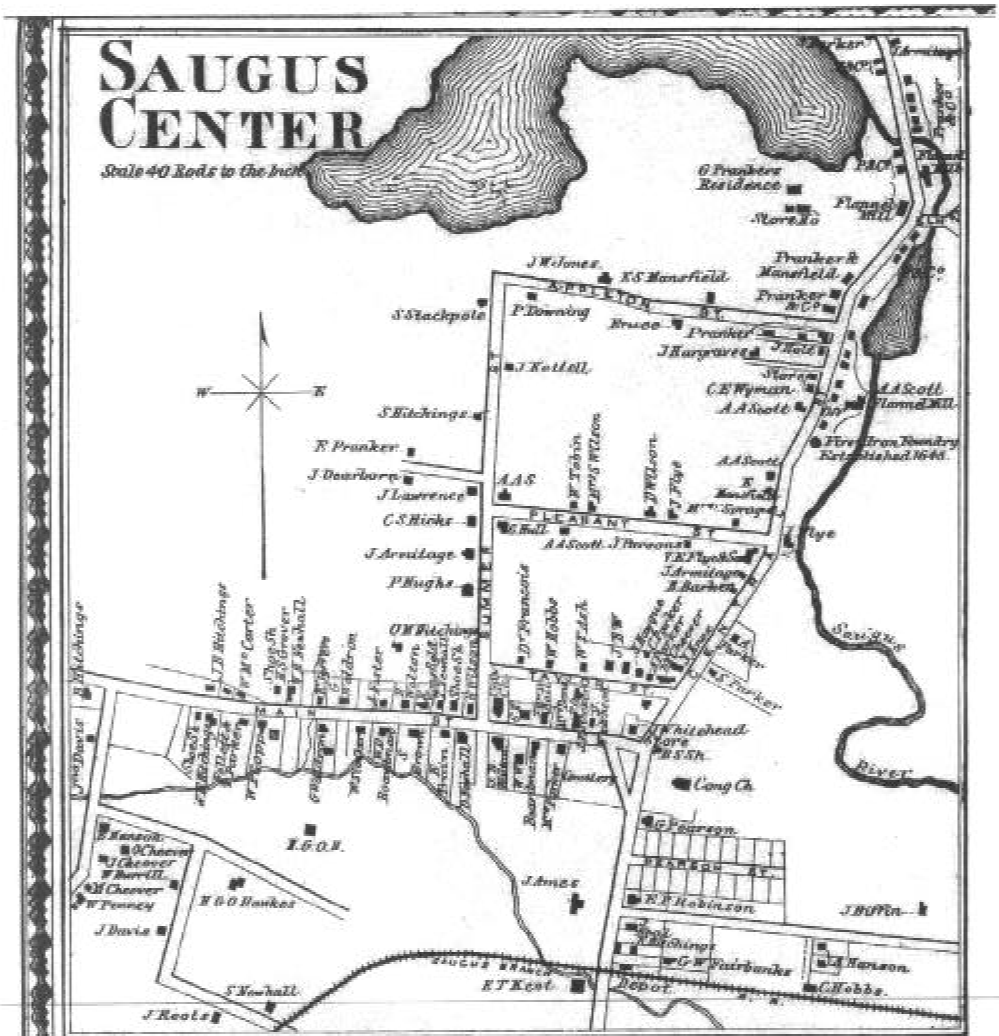


FIGURE 2.5-3



Approximate Saugus River Basin Map from 1867 **FIGURE 2.6-1**



Saugus Center Business Directory.

Pranker & Co...Manufacturers of Flannel Goods.
F. Scott & Son... " " " "
Joseph Whitehead...Dealer in Choice Family Groceries, Country Produce, Crockery, Glass, Wooden and Tin Ware, Corner of Main and Cross Street.
J. E. Stocker...Dealer in Choice Family, Country Produce, Crockery, Glass, Wooden and Tin Ware. Hats, Caps, Boots, Shoes, &c.
W. H. Newhall...Manufacturer of Women's, Misses' and Children's Shoes.
H. S. Grover...Stitcher of all kinds of Boots and Shoes, Slippers a Speciality.
W. P. Copp...Collector.
G. W. Fairbank.. Station Agent.
Geo. Pearson Resident

1872

Town of Saugus Map from 1872 **FIGURE 2.6-2**

3.0 Lynn Water and Sewer Commission Water Supply System

LWSC is the major regulator of flows in the Saugus River, and controls the magnitude and timing of Saugus River flows below the Diversion Dam (except when water flows over the spillway). In this section, LWSC's water sources, peak demand, average daily demand, and reported water withdrawals from the Saugus River are explored. The available data was reviewed with an eye towards those measures that could potentially be used to minimize impacts to aquatic resources caused by diversions from the Saugus River. This includes the timing (monthly) of water withdrawals from the Saugus, water use during peak demand periods, available reservoir storage to supplement low flow periods, water conservation measures and unaccounted for water (leaks).

3.1 Water Sources and Registrations

There are four water sources that are used to meet LWSC demands. They include: Saugus River Diversion, runoff around four LWSC storage reservoirs, Ipswich River Pumping Station and water purchased from the Massachusetts Water Resource Authority (MWRA)[9]. Registrations for water withdrawals are issued by MDEP through the Massachusetts Water Management Act Program, and are summarized in Table 3.1-1.

Table 3.1-1: Summary of LWSC Water Withdrawal Registrations

Water Source	Registered Requirements
Ipswich River Pumping Station	LWSC is registered to withdraw from the Ipswich River an average of 5.31 MGD over the period from December 1-May 31 (180 days) of each year when flows at the Middleton USGS gage exceed 10 MGD.
Saugus River Diversion	LWSC is registered to withdraw from the Saugus River an average of 8.93 MGD throughout the year.
Runoff around four LWSC reservoirs	No registration requirements.
Purchased Water from MWRA	No registration requirements. All purchased water is supplied to General Electric or is used for emergencies

The registered volume from the Saugus and Ipswich Rivers represents the cumulative amount that can be withdrawn in both watersheds. In addition to these allowed withdrawals, LWSC's registration on the Saugus also allows increased withdrawals in 5-year increments so that an additional 1.28 MGD (467.20 MGY) may be withdrawn between September 1, 1999 and August 31, 2009.

As noted in Table 3.1-1, LWSC is registered to withdraw an average of 5.31 MGD from the Ipswich River from December 1-May 31 when flows at the Middleton USGS gage exceed 10 MGD or 15.5 cfs. LWSC has reported that the pumping capacity from the Ipswich River is approximately 15 MGD (LWSC operates the pump at either full capacity or not at all). The Middleton USGS gage is located downstream of the pump (in other words, LWSC controls, to

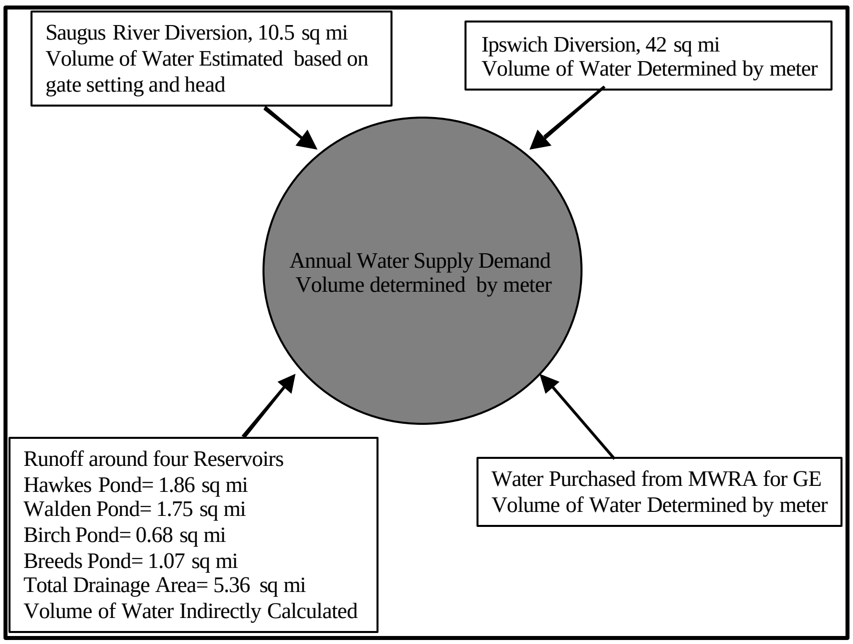
[9] All purchased water is used by General Electric.

some extent, flow at the Middleton gage). To ensure compliance, LWSC pumps water when flow at the Middleton gage is 30 MGD (10 MGD is required, Pump Capacity is 15 MGD, leaving a safety factor of 5 MGD) after pumping. Shown in Figure 3.1-1 is a flow duration curve of the Middleton USGS gage for the period December 1-May 31 (1938-97). Based on the flow duration curve, LWSC can withdraw from the Ipswich River approximately 85-90% of the time throughout this period (as river flows at the Middleton gage are above 15 MGD (or 23.2 cfs) 85-90% of the time).

The layout of the LWSC's water supply system is shown in Figure 3.1-2.

To help understand the water sources and effective drainage areas of each source shown in Figure 3.1-3 is a schematic.

Figure 3.1-3: Schematic of LWSC Water Supply Sources and Effective Drainage Areas

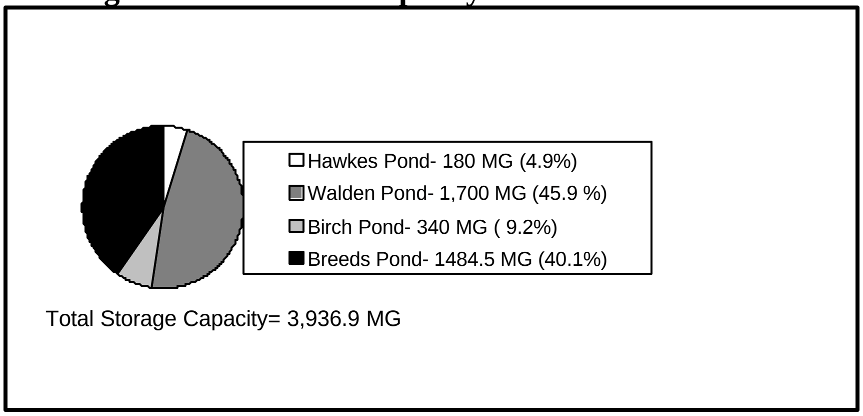


Between the Saugus River Diversion and runoff around the four reservoirs, LWSC controls approximately 15.86 mi^2 (10.5 +5.36) or 68% of the freshwater portion of the Saugus River Watershed at the United States Geological Survey (USGS) gage near the Saugus Ironworks (23.3 mi^2).

Water diverted from the Saugus River is gravity fed via a canal to Hawkes Pond, while water diverted from the Ipswich River is pumped into Walden Pond. Water is pumped from Breeds Pond and/or Birch Pond via a Low Service Pump Station to the Water Treatment Plant and then to the Low Service Reservoir, the distribution system and the distribution storage tanks.

It should be noted that wastewater from the LWSC water distribution system is fed to the Lynn Wastewater Treatment Plant. The plant discharges to the Lynn Harbor, into the ocean. Thus, all water supplied by the LWSC from the Saugus River Basin is eventually discharged out of basin, resulting in a net loss in water volume.

Figure 3.1-4: Usable Capacity of LWSC Reservoirs



The usable storage capacity of each storage reservoir is shown in Figure 3.1-4. The total usable capacity of the storage reservoirs, when full, is approximately 3,936.9 MG or 10.78 MGD (on an annual basis). The usable storage capacity of these reservoirs is almost equal to the average annual demand over the last six years, 3,996 MG. On a volumetric basis, usable storage capacity represents approximately 98.5% of the annual demand.

3.2 Water Demand and Users

LWSC files an Annual Report with the MDEP referred to as "Public Water Supply Annual Statistics Report". Reports between 1994 and 1999 were obtained from LWSC and are shown in Appendix A. A summary of the data contained in those reports is described below. Data for 2000 was not included in the calculations due to the timing of its availability and the project schedule.

- On a monthly basis, LWSC reports the total volume of water metered at: Ipswich Pumping Station, Water Demand (delivered to customers), and purchased water. LWSC also reports the estimated withdraw from the Saugus River, which is computed based on the daily canal sluice gate setting and head across the gate[10]. The runoff volume entering each of the four storage reservoirs is not directly computed.
- On a monthly basis, LWSC reports the total volume of water pumped from Hawkes Pond and the other reservoirs (all metered).
- On an annual basis, LWSC reports the water used by their customers, which is broken down into categories such as residential homeowners, municipal, industrial, commercial, etc.
- On an annual basis, LWSC reports unaccounted water including leaks.

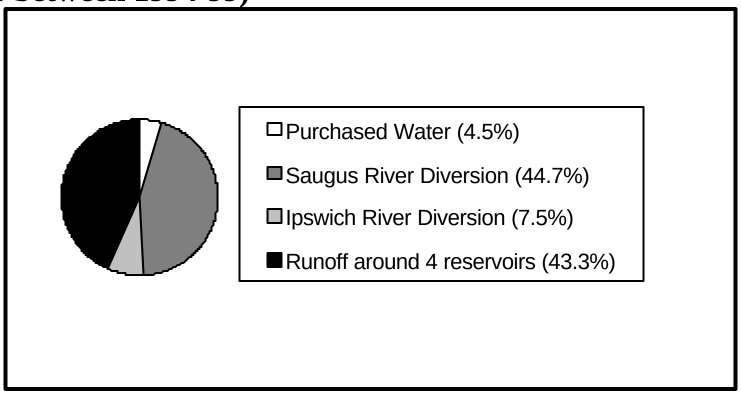
As noted above, runoff entering the four storage reservoirs is not directly measured. However, the runoff volume can be indirectly approximated based on the equation below and <u>under the assumption</u> that the storage capacity of the four storage reservoirs at the start and end of the year is the same.

[10] This practice of estimating Saugus River withdrawals has been used over the past few years (Personal Communication, Rick Dawe, LWSC)

Total Demand= Saugus Diversion+Ipswich Diversion+Purchased Water+Net Runoff around 4 Reservoirs (runoff less pond evaporation)&Other Underdetermined Sources

Using this equation, the percentage of water taken from the various sources was estimated as shown in Figure 3.2-1 (detailed calculations are shown in Appendix B).

Figure 3.2-1: Percentage of Water Taken from Various Water Sources to Meet Demand (based on averages between 1994-99)



As the pie chart depicts, over 88% of the water supply is provided by the Saugus River Diversion and from runoff around the four reservoirs on an annual basis. As noted above, the runoff around the four reservoirs (drainage area = 5.36 mi^2) was indirectly calculated, however, the runoff volumes appear high. The net average annual flow around the four reservoirs equates to approximately 29.5 cfs (or 5.5 cfsm). This is an unusually high average annual flow volume, relative to the drainage size. Therefore, there are likely other factors that are not taken into account in the above equation, but are also not measurable including: spill at the reservoirs returning flow back to the Saugus River Basin, evaporation, and inaccuracies in other variables in the above equation.

To further describe the amount of water used from the four major sources, shown in Figure 3.2-2 is a bar chart depicting total annual demand (MGY), average daily demand (MGD) and peak daily demand (MGD) for 1994 through 1999. Water usage over these six years has been consistent averaging 3,996 MGY and ranging between 3,823 MGY (10.5 MGD) and 4,075 MGY (11.2 MGD). The peak demand has ranged from 14.03 MGD to 15.20 MGD, which occurs primarily during the summer months when water usage is traditionally higher (lawn watering, car washes, filling swimming pools, etc). LWSC's Direct Filtration Plant is designed for an average daily flow of 15.3 MGD with a peak of 23.0 MGD.

Shown in Figure 3.2-2 is the average annual demand and peak demand for years 1994-1999. Over these six years, the peak demand has occurred during the summer in June (3), July (2) and August (1). The average difference between the annual average demand and peak demand over the last six years is approximately 3.68 MGD. The ratio of peak demand relative to average annual demand is 1.35. This ratio suggests that the LWSC peak demand does not vary considerably to the average annual demand. Although the state does not record the peak/average annual demand factors, many parties believe a factor of 1.35 is low. A frame of reference may be the Ipswich Watershed Association's rating of factors as follows (the higher the grade the less variability between average annual demand and peak demand):

A = <1.25
B= 1.25 to 1.50 (Saugus 1.35)
C= 1.50 to 1.75
D= 1.75 to 2.00
F= 2. 00 >

LWSC reports the amount of water delivered to its various customers, which includes residential, commercial, industrial, etc as shown in Table 3.2-1.   Approximately 50% of LWSC's water (1,974 MGY or 5.4 MGD based on the 1994-99 average) is supplied to residential homeowners, with the balance distributed among commercial, municipal, industrial and process needs (water used for flushing, filter backwashing, etc). The population served is approximately 81,000 residents in the City of Lynn. Dividing the average daily water use (5.4 MGD) by the residents served (81,000) results in a 66.8 gallons per capita day (gpcd). According to MDEM, this value only slightly exceeds the state's water conservation goal of 65 gpcd for residential use (Ref: Interbasin Transfer Act, Performance Standards Guidelines).

Unaccounted for water was also examined to determine if leakage was sizeable, since this affects the amount of water taken from the Saugus River and other sources. Unaccounted for water reported since 1996 is shown in Table 3.2-2.

Table 3.2-2 Unaccounted for Water in Millions of Gallons (MG)

Source	1999	1998	1997	1996
Leaks % of Total Demand	170 4.5%	*71 --	71 1.8%	249 6.1%
Meter Calibration	280	636	575	154
Fire Protection	25	25	25	25
Construction and Sweeping	2	2	53	7
WWTP Meter	0	0	0	292

* Estimate based on 1997
Note: No Data was provided for leaks in 1994 and 1995

The percentage of system leakage relative to the water consumed (demand) ranges from roughly 2-6%. These values meet the state's water conservation goal of less than 10 %. LWSC conducts leak detection surveys every two years on their entire distribution system to locate and repair leaks on a priority basis.

LWSC also reports the volume of water pumped from Hawkes Pond (metered), and the volume of water diverted from the Saugus River (estimated) on a monthly basis. The pumping and diversion records were reviewed to determine if the estimates of water withdrawals appeared reasonable. Presumably, the water diverted from the Saugus River should be close to the amount pumped from Hawkes Pond. An annual summary of the past six years is provided in Table 3.2-3.

Table 3.2-3: Water Diverted from Saugus River and Water Pumped from Hawkes Pond

Year	Annual Volume Diverted from Saugus River (MG)	Annual Volume Pumped from Hawkes Pond (MG)	Net Difference (MG) (Percent Difference,%)
1999	1,858	1,948	-90 (5%)
1998	1,961	2,075	-114 (5%)
*1997	1,532	1,327	205 (15%)
1996	1,590	2,196	-606 (28%)
1995	1,684	1,980	-296 (15%)
1994	2,100	2,538	-438 (17%)
Average	1,788	2,011	-223 (11%)

* Note that in January 1997, LWSC lowered Hawkes Pond via two 12-inch pumps through the spillway in response to an emergency conditions related to dam stability. The positive "net difference" shown in Table 3.2-3 can be attributed to this operation.

LWSC indicated that the water diverted from the Saugus River is determined based on the canal gate opening and head at the dam. Water pumped from Hawkes Pond is metered so accurate water volumes are recorded daily. The difference between water diverted from the Saugus River and that pumped from Hawkes Pond is due to a combination of factors including: pond evaporation, runoff from the drainage area around Hawkes Pond (1.86 mi^2), spill at Hawkes Pond, and the assumption that the pond elevation is the same at the start and end of the year (which isn't always true)[11]. Water pumped from Hawkes Pond should be greater than water diverted from the Saugus since runoff from the Hawkes Pond watershed is probably greater than pond evaporation. Estimates of Saugus River diversions in the last three years appear conservative (more than perhaps was truly taken) given that the agreement is 5%, 5% and 15%, respectively. Overall, the annual withdrawal reported by LWSC from the Saugus appears reasonable.

3.3 Seasonal Water Use and Sources

The seasonal demand of water was evaluated to determine if LWSC Saugus River diversions could be reapportioned throughout the year (less water taken in the summer and more during spring). Shown in Figure 3.3-1[12] is a stacked bar graph depicting, by month, the water sources used from: Saugus River Diversion, purchased water, Ipswich River Diversion and a combination of runoff around the four reservoirs and reservoir storage. Keep in mind that runoff around the reservoirs was only estimated, and appears to be unusually high for such a small drainage area. The analysis also assumes that the reservoir storage at the start and end of each month is the same. This is not true when examining monthly runoff since reservoir storage varies. As Figure 3.3-1 shows, runoff around the four reservoirs is "negative" in the winter.

[11] LWSC can release water fromHawkes Pond using the following means: 1) Pumping water into Walden Pond, which is normal practice, 2) Gravity feed backwards to the Saugus River Diversion Dam, 3) Operation of a 30-inch sluice gate, which discharges into a wetland connected to Hawkes Brook (this operation is rarely used due to limitations associated with minor downstream flooding) ,and (4) Operation of a 36-inch sluice gate into Hawkes Brook located downstream from Spring Street. Again, this would only be used during an emergency.
[12] Data used to develop Figure 3.3-1 is shown in Appendix B.

This likely occurs because runoff is being stored and the reservoirs refill for the next summer's demand. In December and January, it appears that the water used to refill the reservoirs exceeds runoff around the four reservoirs, hence the negative values. During the summer, reservoir storage is used primarily to supplement water demands and is the major water source for meeting demand. Also, per LWSC's registration, no Ipswich River water withdrawals are allowed during the period June 1-November 30.

To better understand the use of reservoir storage in meeting demand, shown in Figure 3.3-2 is a plot of reservoir storage use versus month for Breeds, Birch, Hawkes and Walden Reservoirs. Also shown in the plot (as a bar graph) is the average Saugus River withdrawal. The storage capacity and Saugus withdrawals are averages based on the period 1994-1999. As Figure 3.3-2 shows Breeds and Walden Reservoirs provide the majority of storage capacity in the system. These two reservoirs are near full capacity in May and June, and then are drawn down over the summer to meet demand. The lowest drawdown elevation typically occurs in October or November. The reservoirs are refilled during the December-April period via the Saugus and Ipswich River Diversions and spring runoff.

The seasonal water demand and Saugus River withdrawals were compared as shown in Figure 3.3-3. Water demand is highest during the summer and gradually drops off in the early fall and winter. The seasonal Saugus River withdrawals reflect an opposite trend, where the lowest withdrawals occur during the summer, and highest in the fall and winter. LWSC has noted that summer withdrawals are typically limited to short periods following significant precipitation events. Interestingly, withdrawals during the traditional high runoff period, March and April, are not higher. It is assumed that higher withdrawals from the Saugus River do not occur in the spring as water from the Ipswich River plus runoff around the reservoirs contributes to refilling the storage reservoirs. In summary, LWSC withdrawals the least amount of water from the Saugus in the summer, and relies on reservoir storage to meet summer demand.

3.4 Water Conservation

LWSC has developed a Water Conservation Policy and Drought Contingency Plan in case of drought conditions. The full policy is in Appendix C, however, the highlights are described here. The plan has triggers based on the percentage of available reservoir storage where water conservation measures occur as summarized in Table 3.4-1

Table 3.4-1: Summary of Water Conservation Policy

Trigger	Water Conservation Measures
Normal Condition (66-100% Capacity)	No public restrictions, repair leaks, operators pump and draw from source rivers as reservoir and seasonal conditions allow
Drought Watch (56-65% Capacity)	Same as above. Water Supply Superintendent begins monitoring reservoir levels, usage, and supply on weekly basis
Voluntary Curtailment (51-55% Capacity)	Same as above. Newspaper ads requesting voluntary reduction. LWSC will request permission to pump from Ipswich during prohibited times when water is available

Trigger	Water Conservation Measures
Limited Restrictions (46-50% Capacity)	Same as above. Newspaper ads placed requesting water conservation measures (lawn sprinkling, car washing, filling swimming pools, etc)
Enforced Bans (26-45% Capacity)	Same as above. More aggressive newspaper ads prohibiting or restricting water use. Issue warnings for first offenses and fines or termination of service for repeated violations. Rebates are offered or other incentives to large volume users who substantially reduce their consumption.
Declared Water Emergency (<25% Capacity)	Same as above. Newspaper ads placed to ban all unnecessary water usage. Rebates are offered or other incentives to all users who substantially reduce their consumption.

Rick Dawe of LWSC indicated that in 1999 warnings were effective as water usage dropped during low storage periods. Rick noted that the average daily demand steadily dropped from 12.4 MGD during the week of July 3rd to 9.8 MGD during the week of August 25th as more stringent restrictions were taken. During the summer of 1999 the "Limited Restrictions" trigger level was reached. MDEP was notified of this event.

When water supply levels are in the 46-50% range of capacity (Limited Restriction), LWSC can request permission from the MDEP to withdraw additional water from the Ipswich River.

3.5 LWSC's Decision-Making Process for making Saugus River withdrawals

LWSC regulates the water from the Saugus River as seasonal variations and water supply storage levels warrant. Rick Dawe of LWSC provided the following information on how Reedy Meadows water elevations (behind the Diversion Dam) and Saugus River withdrawals are managed over the seasons. Note that reference to dam water levels below, refers to the water elevation behind the Diversion Dam or the pool elevation at the end of Reedy Meadows.

Summer: During the summer, the dam water level is maintained between elevation 74'10" and 75'8" (local datum) by closing the gates. Opening the gates (especially the Diversion Dam gate) at this time may result in rapid draw down of water levels in the nearby portions of the meadow. During this period, heavy urban water use can result in drawing from LWSC's four storage reservoirs. Under high precipitation events, the canal gate may be opened to divert water to Hawkes Pond.

Fall: As precipitation becomes more evident, the water level at the dam is maintained between 75'3" and 76' by regulating the canal gate. During this period, LWSC's water supply capacity may be quite low from summer usage. As such, all available water is diverted to Hawkes Pond to refill the reservoirs.

Winter: During the early winter, the water level at the dam is maintained between 75'8" and 76'4" by regulating the canal gate. During this period, LWSC may try to fill its water supply reservoirs by diverting water through the canal. However, during extremely wet events the Diversion Dam gate may be opened to control elevations. During the late winter, the water level at the dam is maintained between 75'8" and 76'4" by regulating both the canal and Diversion Dam gates. LWSC's water supply reservoirs are normally between 75 –90% full at this time.

Spring: During the spring, water levels at the dam are between 74'10" and 76' depending on flow conditions. During and after significant precipitation events, adjusting the Diversion Dam gate may regulate the water level. Since most of the water in the meadow is trapped, the water elevation may drop far more substantially than further upstream locations (which can be subject to flooding). As such, the Diversion Dam gate must be periodically adjusted to accommodate upstream residents. The reservoir system is normally between 90-100% full. Water may be taken sparingly to "top off" reservoir levels. During extremely wet periods and dependent on meadow conditions, Hawkes Pond may be fed backwards through the canal and Diversion Dam gates to lower the reservoir level. Consideration is also given to adjusting flow through the Diversion Dam to protect downstream areas from flooding.

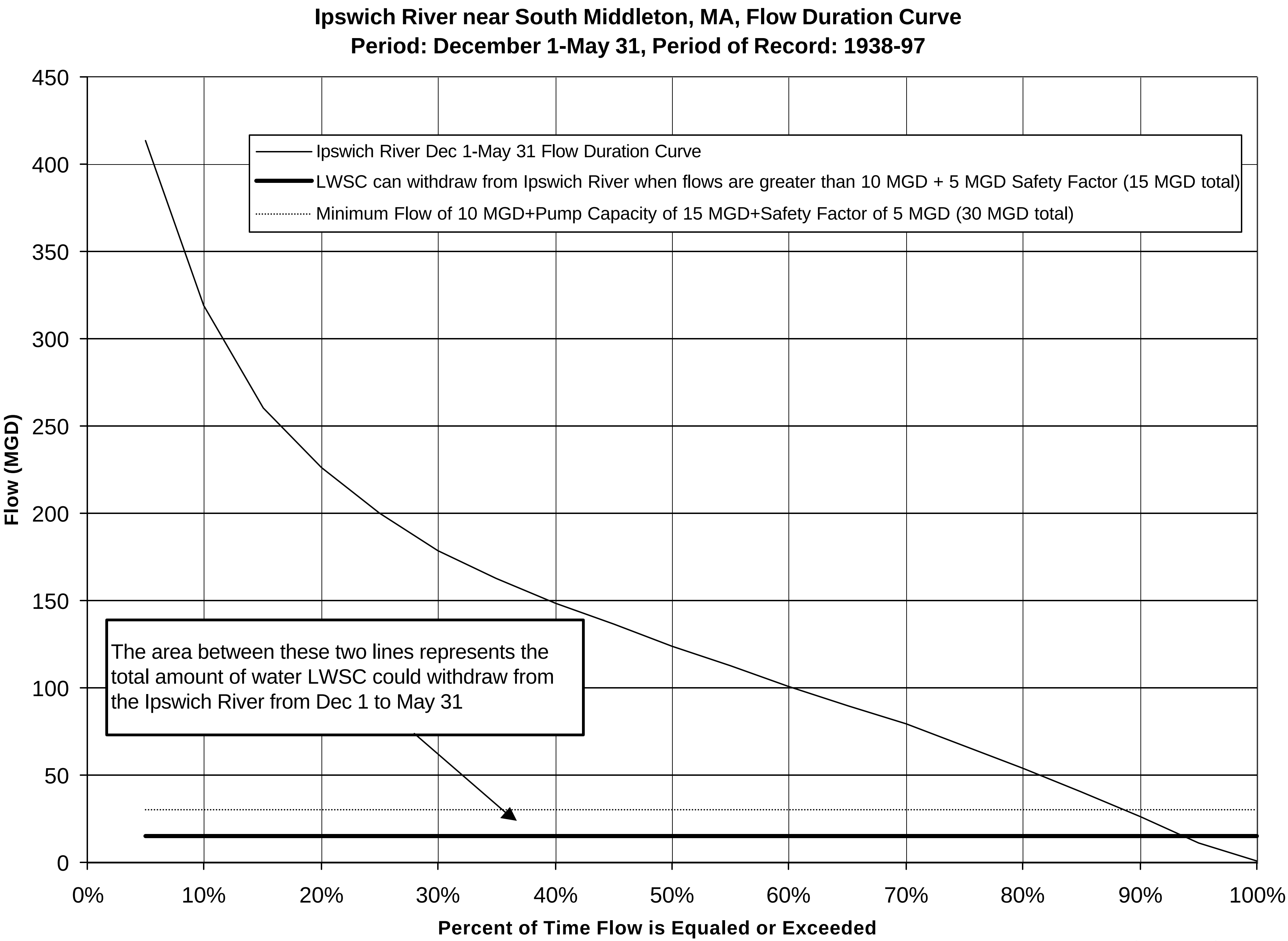
LWSC records the water surface elevation in the Reedy Meadows headpond as well as in the canal. Using the Reedy Meadows headpond data, the average, maximum and minimum elevation was computed on an annual basis as shown in Figure 3.5-1. The headpond elevation typically fluctuates between elevations 75 and 76 feet, but rises during the spring runoff. Shown in Figure 3.5-2 is a similar plot for the canal water surface elevation. The canal elevation typically fluctuates between elevations of 74 to 75 feet. The canal water surface elevation is highest during the spring, which appears reasonable given that diversions occur more frequently during this period to refill the storage reservoirs. Alternatively, canal water surface elevations are lowest during the summer. Lastly, shown in Figure 3.5-3 is the average headpond and canal water surface elevations based on the same January 1, 1988 to May 31, 2000 record. The difference between these curves represents the average head across the canal sluice gate.

Table 3.2-1: Breakdown of LWSC Water Users and Water Use in Millions of Gallons per Year

	1994	% of Total	1995	% of Total	1996	% of Total	1997	% of Total	1998	% of Total	1999	% of Total
Annual Demand	4037		4013		4075		4020		4006		3823	
Residential	1965	48.7%	2006	50.0%	1950	47.9%	1936	48.2%	1944	48.5%	2044	53.5%
Other Semi-Residential		0.0%		0.0%		0.0%		0.0%		0.0%	498	13.0%
Commercial	427	10.6%	437	10.9%	460	11.3%	464	11.5%	452	11.3%	435	11.4%
Municipal	480	11.9%	593	14.8%	366	9.0%	448	11.1%	465	11.6%	0	0.0%
Industrial	349	8.6%	313	7.8%	328	8.0%	267	6.6%	212	5.3%	186	4.9%
Process	0	0.0%	0	0.0%	261	6.4%	181	4.5%	199	5.0%	0	0.0%
Other		0.0%		0.0%		0.0%		0.0%		0.0%	183	4.8%
Unaccounted For	816	20.2%	664	16.5%	710	17.4%	724	18.0%	734	18.3%	477	12.5%

* Other Semi-Residential Use= Municipal Water Use such as City Hall, School Department, etc. Previous DEP reporting forms contained a line item for Municipal Water Usage. The 1999 report did not and thus usage was placed under "Other Semi-Residential Use".

Source : LWSC Annual Statistics Reports 1994-1999



Ipswich River near South Middleton, MA, Flow Duration Curve
Period: December 1-May 31, Period of Record: 1938-97
Ipswich River Dec 1-May 31 Flow Duration Curve
LWSC can withdraw from Ipswich River when flows are greater than 10 MGD + 5 MGD Safety Factor (15 MGD total)
Minimum Flow of 10 MGD+Pump Capacity of 15 MGD+Safety Factor of 5 MGD (30 MGD total)
The area between these two lines represents the total amount of water LWSC could withdraw from the Ipswich River from Dec 1 to May 31
Flow (MGD)
0
50
100
150
200
250
300
350
400
450
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Percent of Time Flow is Equaled or Exceeded

FIGURE 3.1-1

LYNN WATER AND SEWER COMMISISION
LAYOUT OF WATER SUPPLY SYSTEM

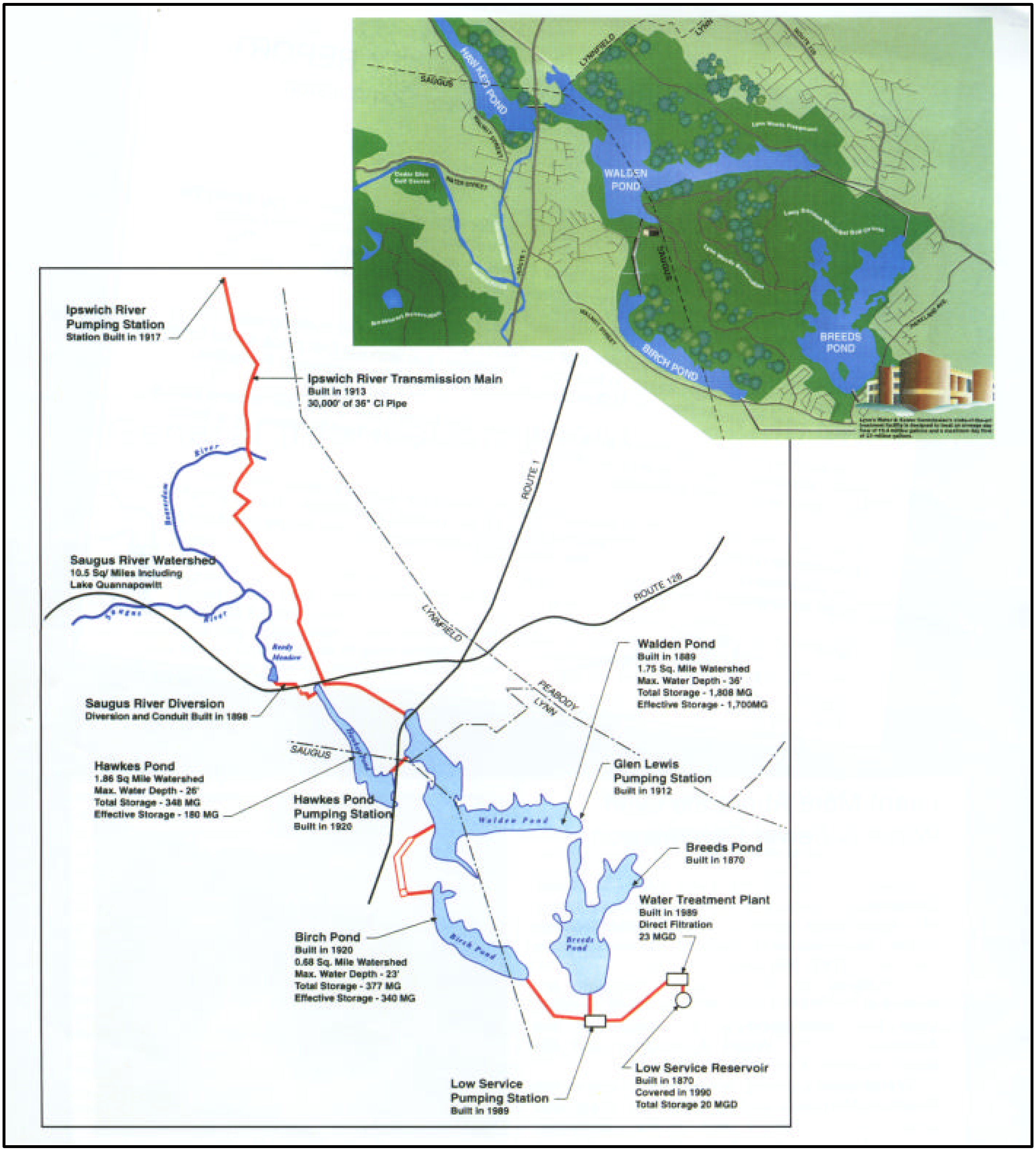
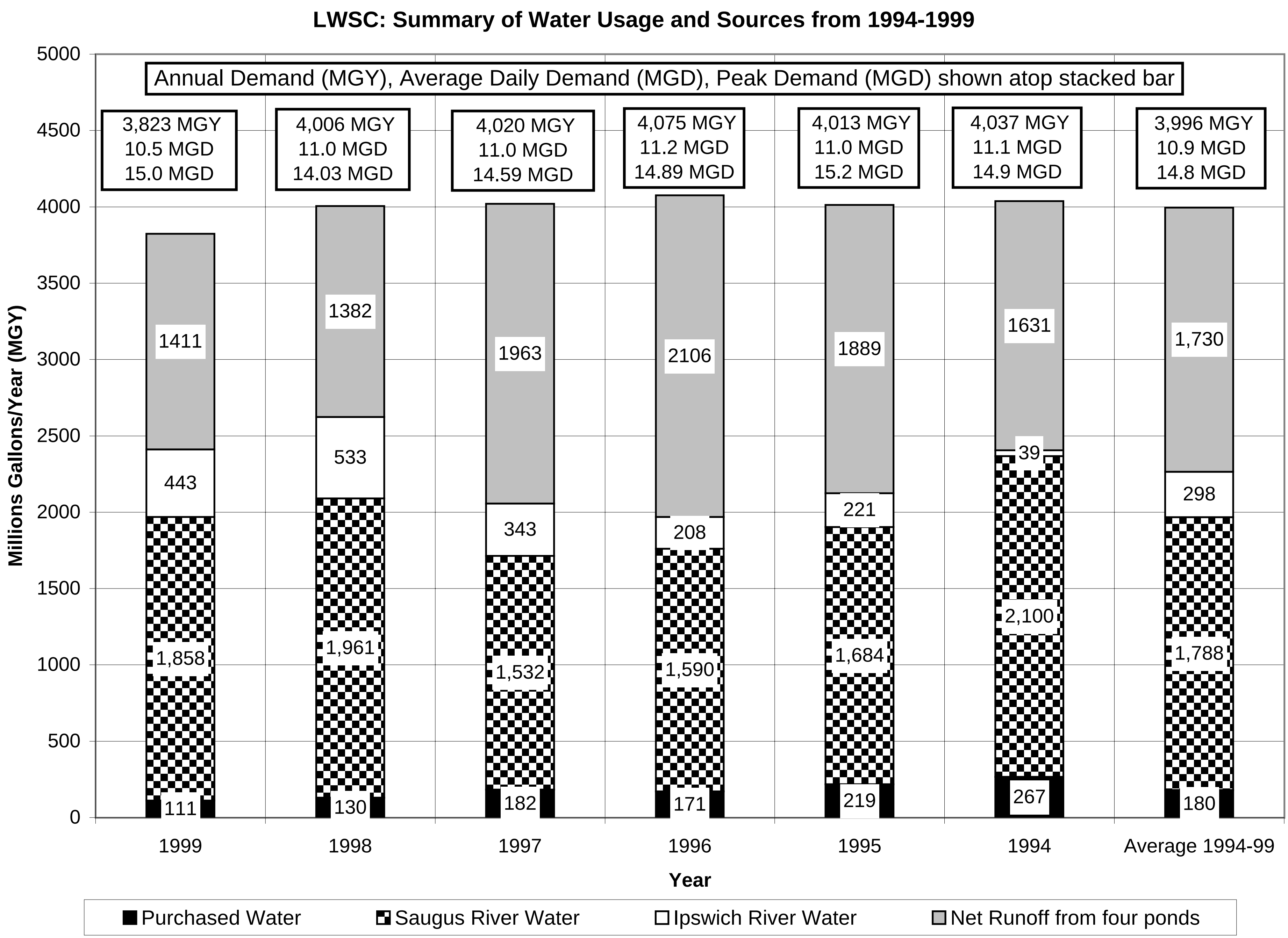


FIGURE 3.1-2



Assumes that the storage capacity is the same at the beginning and ending of each year.

FIGURE 3.2-2

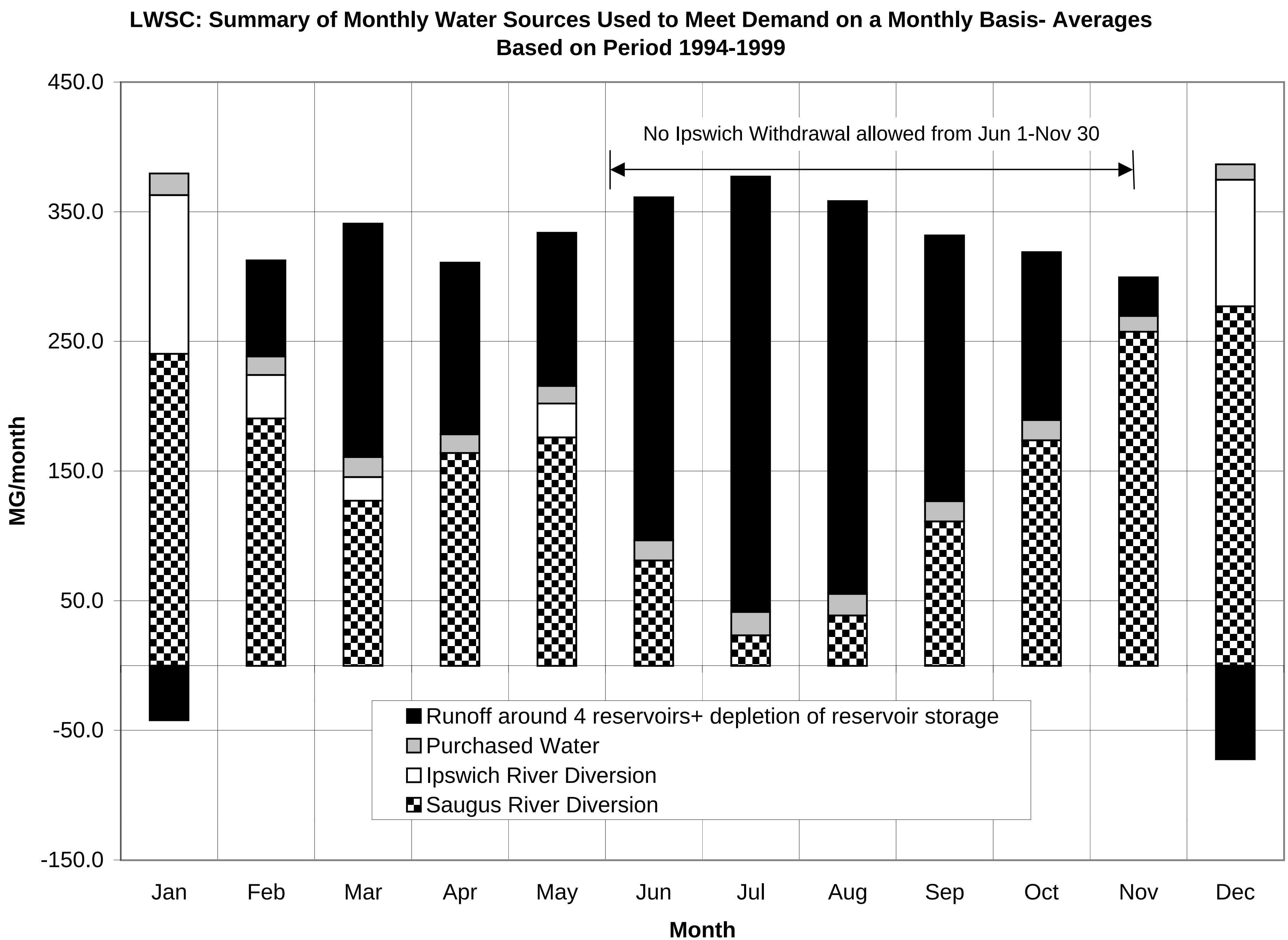

LWSC: Summary of Monthly Water Sources Used to Meet Demand on a Monthly Basis- Averages
Based on Period 1994-1999
No Ipswich Withdrawal allowed from Jun 1-Nov 30
MG/month
450.0
350.0
250.0
150.0
50.0
-50.0
-150.0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Runoff around 4 reservoirs+ depletion of reservoir storage
Purchased Water
Ipswich River Diversion
Saugus River Diversion

FIGURE 3.3-1

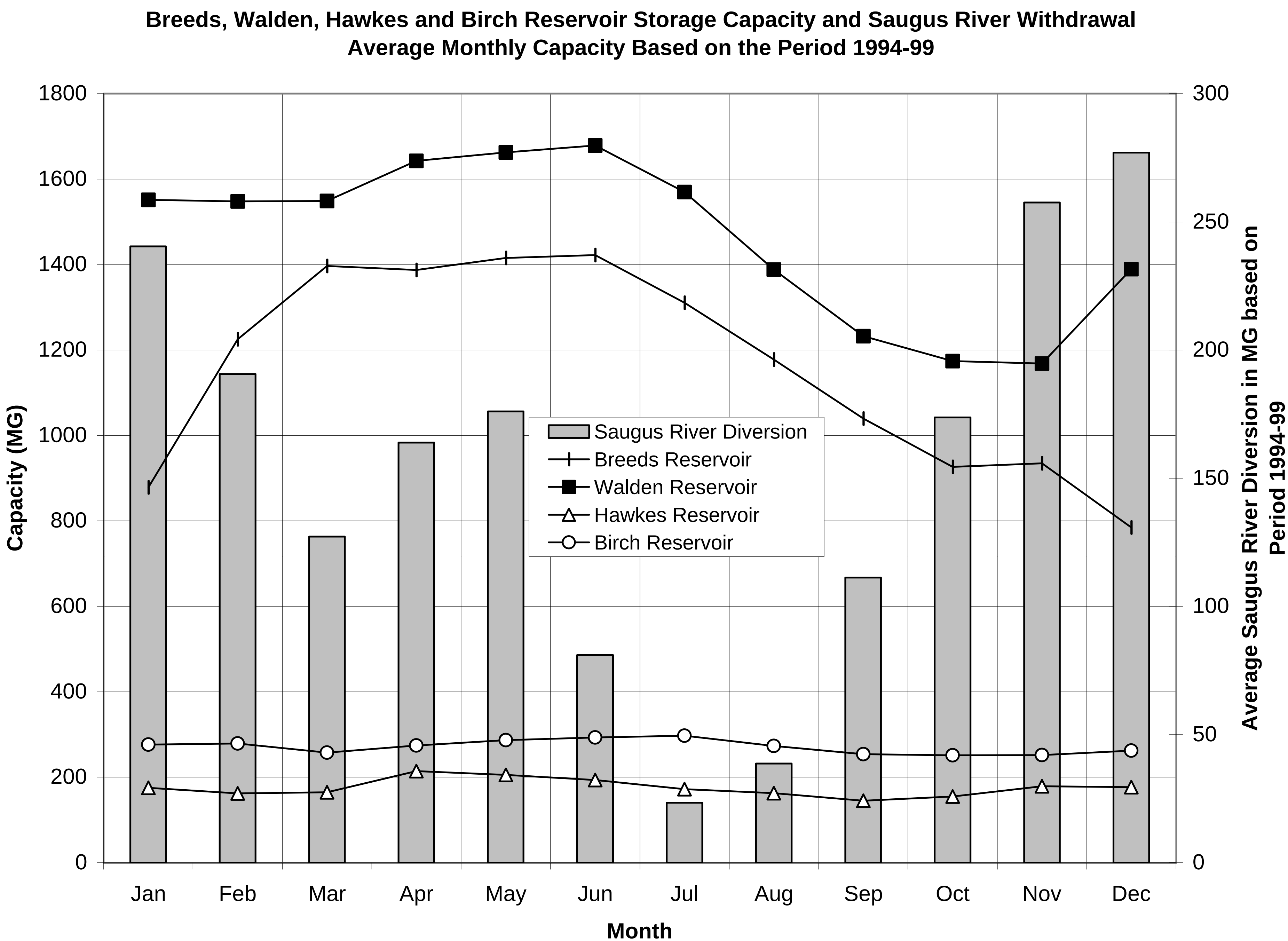

Breeds, Walden, Hawkes and Birch Reservoir Storage Capacity and Saugus River Withdrawal
Average Monthly Capacity Based on the Period 1994-99
Capacity (MG)
Average Saugus River Diversion in MG based on Period 1994-99
Month
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
0
200
400
600
800
1000
1200
1400
1600
1800
50
100
150
200
250
300
Saugus River Diversion
Breeds Reservoir
Walden Reservoir
Hawkes Reservoir
Birch Reservoir

FIGURE 3.3-2

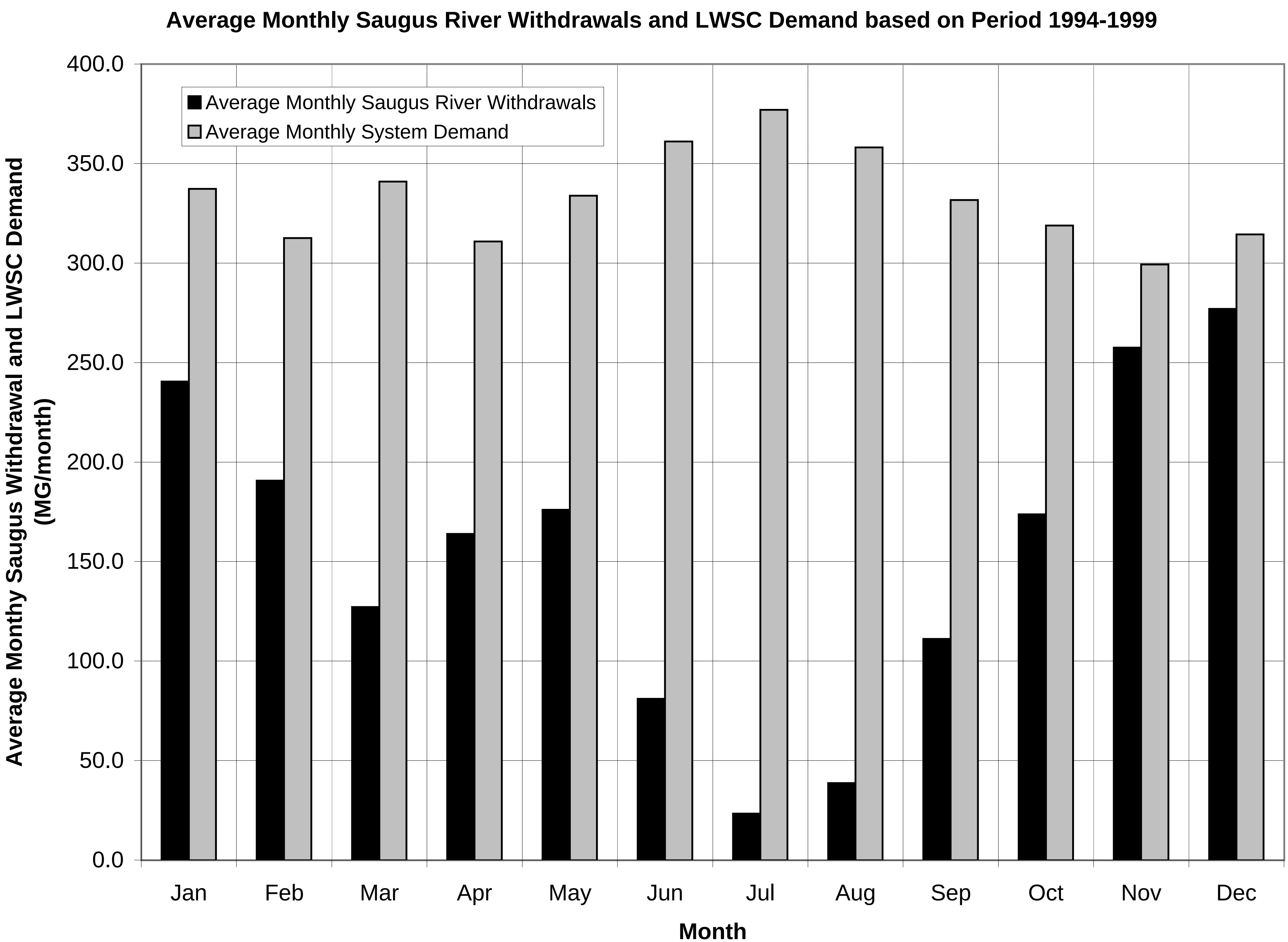

Average Monthly Saugus River Withdrawals and LWSC Demand based on Period 1994-1999
Average Monthly Saugus River Withdrawals
Average Monthly System Demand
Average Monthy Saugus Withdrawal and LWSC Demand (MG/month)
400.0
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

FIGURE 3.3-3

Reedy Meadows Headpond Elevation Data (Average, Maximum and Minimum Elevations Based on Period of Record: January 1, 1988 to May 31, 2000)

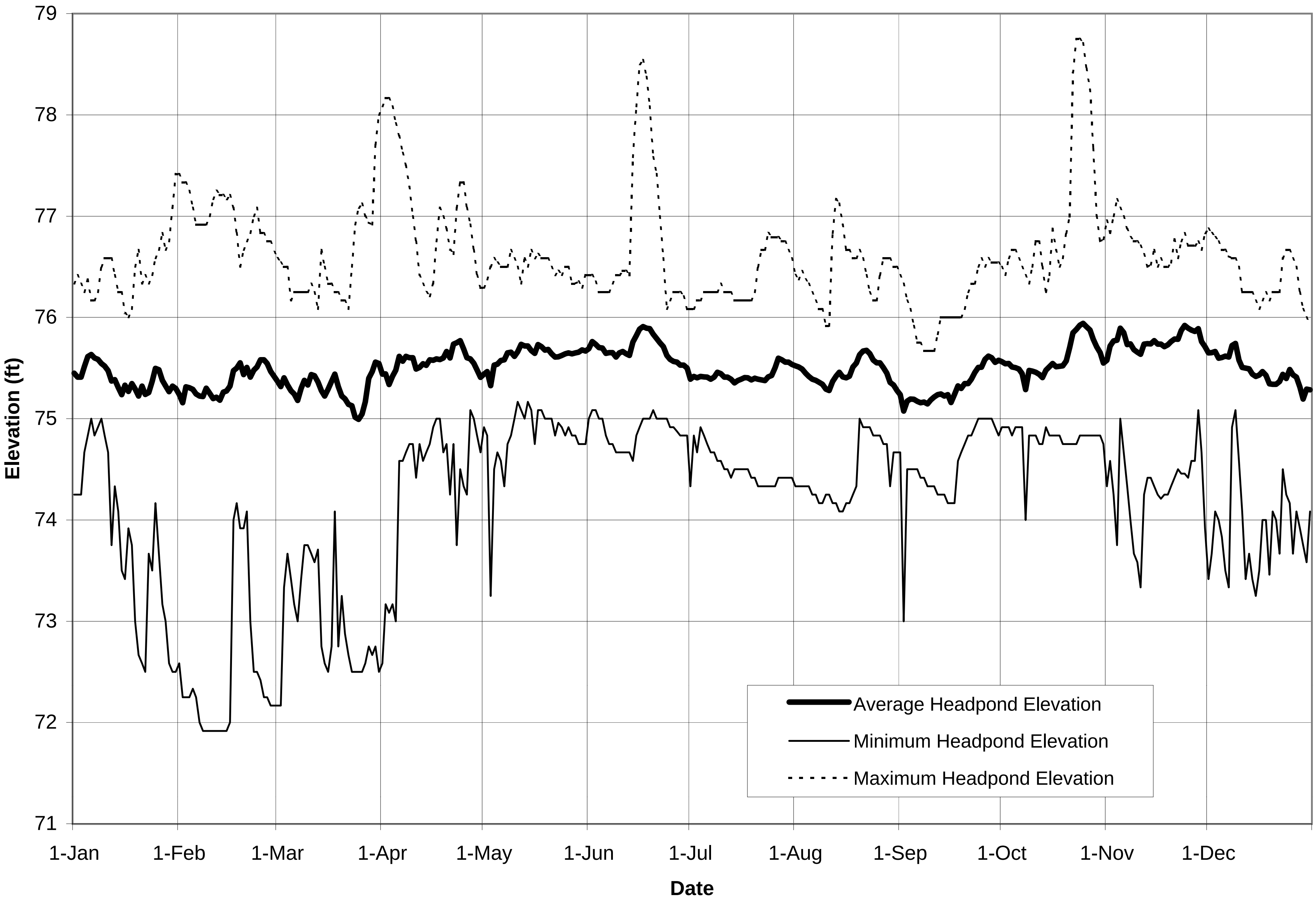


FIGURE 3.5-1

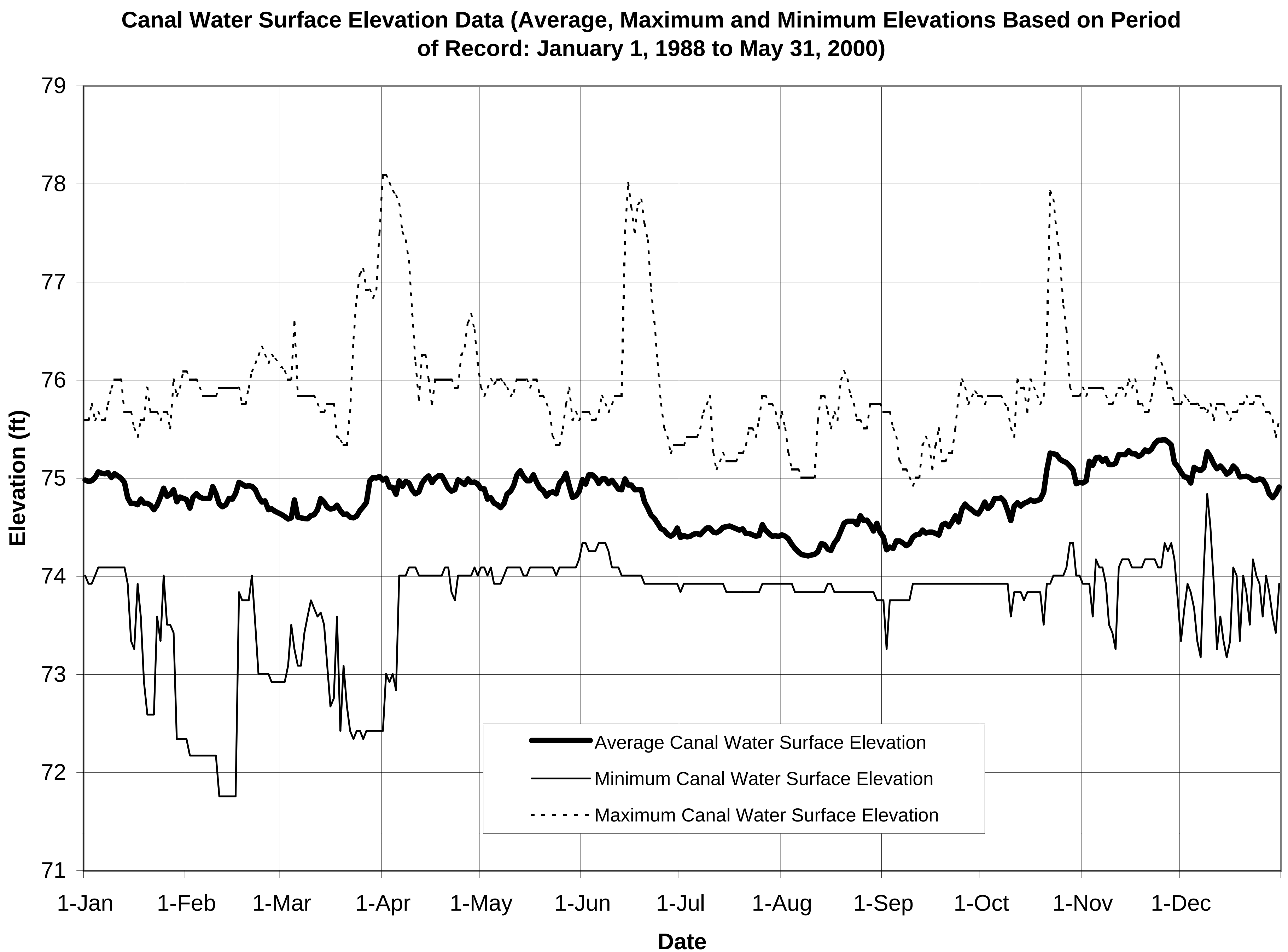
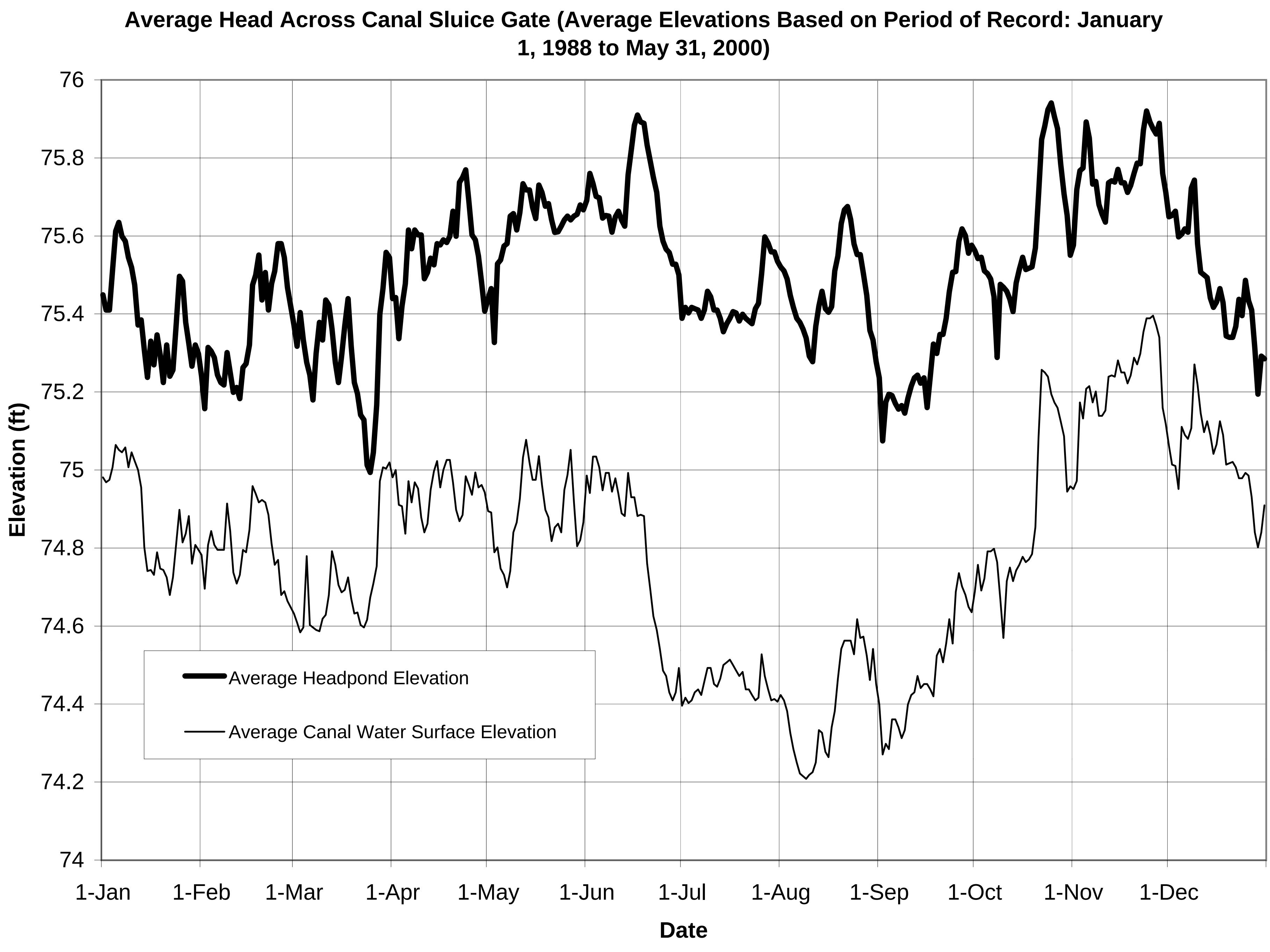

Canal Water Surface Elevation Data (Average, Maximum and Minimum Elevations Based on Period of Record: January 1, 1988 to May 31, 2000)
79
78
77
76
75
74
73
72
71
Elevation (ft)
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
Date
Average Canal Water Surface Elevation
Minimum Canal Water Surface Elevation
Maximum Canal Water Surface Elevation

FIGURE 3.5-2



Average Head Across Canal Sluice Gate (Average Elevations Based on Period of Record: January 1, 1988 to May 31, 2000)
Elevation (ft)
76
75.8
75.6
75.4
75.2
75
74.8
74.6
74.4
74.2
74
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
Date
Average Headpond Elevation
Average Canal Water Surface Elevation

FIGURE 3.5-3

4.0 Other Registered Water Withdrawals and Summary of All Registered Withdrawals

As described in Section 3.0 LWSC controls the flow regime below the Diversion Dam. However, there are three other registered water withdrawals that also impact the Saugus River flow regime including: the Sheraton Colonial Golf Course for greens watering, the Lynnfield Center Water District (LCWD) for residential needs, and the Wakefield Water Department (WWD), which withdrawals water from the Saugus Basin and also imports water . These water users are described below.

It should be noted that there are likely other groundwater withdrawals in the Saugus Basin, however, because the withdrawal volumes are less than 100,000 gallons/day, no registration or permit is required. The cumulative effect of these withdrawals on the Saugus River flow regime is unknown, but it is likely less than that of the larger users. In addition most of these withdrawals would be obtained via wells and thus the majority of water would be discharged back to the system (except during the summer due to lawn watering, and any other activity that would result in evapotranspiration[13] and evaporation)

4.1 Sheraton Colonial Golf Course

The Sheraton Colonial Golf Course is located within the Saugus Basin, near the LWSC Diversion Dam. Water withdrawals are made from an unnamed pond and are used to maintain greens. In August 2000, the MDEP approved the transfer of the original registration, issued in February 1991, from Flatley Company to Starwood Hotels and Resorts Worldwide, Inc. The current registration (No. 9P-3-18-164.02) authorizes the withdrawal of 0.20 MGD or 30.60 MGY over the period May 1-September 30 (153 days) of each year. The registration continues through August 31, 2009.

Water withdrawal records for the past seven years (1993-1999, absent 1996) were obtained from MDEP (see Appendix D for the Annual Reports). Interestingly the reports show the same monthly withdrawal each year as summarized in Table 4.1-1.

Table 4.1-1: Sheraton Golf Course, Total Monthly Withdrawals for 1993-99, absent 1996

Month	Total Water Withdrawn in MG
Jan-Mar and Dec	0.0 (0.0 MGD)
Apr	2.5 (0.08 MGD)
May	3.0 (0.10 MGD)
Jun	3.5 (0.12 MGD)
Jul	3.5 (0.11 MGD)
Aug	3.5 (0.11 MGD)
Sep	2.5 (0.08 MGD)
Oct	1.5 (0.05 MGD)
Nov	0.5 (0.02 MGD)
Total	20.5 MGY (0.08 MGD)

[13] Evapotranspiration is the loss of water from the soil both by evaporation and by transpiration from the plants growing thereon.

Because of natural hydrologic variability, it is questionable whether the same water withdrawal volume is truly taken (or necessary) each month or if the withdrawals are not metered but estimated.

The current registration also allows for withdrawals from May 1- September 30, however, the annual reports show withdrawals in April and November as well. The following statement is contained in the MDEP permit: "Please be advised that if irrigation of the Course is required outside of this period (May-September), the total water withdrawal from the Unnamed Pond shall not exceed 0.1 MGD". Given this provision, the April and October-November withdrawals are within the requirements.

Based on the reported withdrawals, the golf course utilizes approximately 67% of their authorized withdrawal.

Water withdrawals are not used for consumptive purposes, and thus a percentage of the water withdrawn presumably recharges groundwater. MDEM has approximated that 50% of the water used for greens watering during the period May-September is returned via groundwater to the Saugus River, with the balance being lost to evaporation and evapotranspiration. Shown in Figure 4.1-1 is the estimated amount of water returned and lost (evaporation, etc.) from the watershed.

4.2 Lynnfield Center Water District

As noted earlier, the Lynnfield Center Water District (LCWD) operates three wells located south of Beaverdam Brook, on the southeastern edge of a large wetland area. Two wells are within a short distance of each other and are referred to as Station 3, while the other well is referred to as Station 1 (the tubular wellfield is commonly referred to as the Phillips Road Wellfield). The drainage area of Beaverdam Brook, at the confluence with the Saugus River, is approximately 2.56 square miles. Well water is used to serve the residential community in the Beaverdam Brook area.

Station 1 is one of three water supplies serving the LCWD located in Lynnfield, MA. Originally constructed in the 1940's and 50's, Station 1 was reconstructed with 59 new tubular wells in 1983. No other wells are located within a 1000-foot radius of Station 1. However, Station 3 is located within one-half mile of Station 1. Because of high manganese and iron concentrations, Station 3 is only used during high demand periods. There are approximately 30 additional wells located within a half-mile radius of the site; however, these private wells are all used for domestic purposes.

MDEP issued a permit (No. 9P2-3-17-164.01) to LCWD in August 2000, effective through August 2009. The registration applies to Stations 1 and 3 in the North Coastal Basin and Stations 2 and 4 in the Ipswich River Basin. The current registration allows LCWD to withdraw 0.32 MGD (combined Stations 1 and 3) from the North Coastal Basin and 0.29 MGD (combined Stations 2 and 4) from the Ipswich River Basin. The withdrawal volumes, 0.32 and 0.29 MGD, reflect an annual average daily volume. The registration stipulates that the maximum daily withdrawal volumes will be limited to the approved capacity of each well, which follow:

Station 1 (North Coastal Watershed) 0.27 MGD*
Station 2 (Ipswich River Watershed) 0.15 MGD*
Station 3 (North Coastal Watershed) 0.17 MGD*
Station 4 (Ipswich River Watershed) 0.24 MGD*
* Combined daily withdrawal volumes must not exceed 0.83 MGD.

The registration contains a special condition requiring LCWD to submit a report detailing their water use from January 1-June 30 each year. If the total volume withdrawn exceeds 140 MG by June 30, LCWD is required to develop a plan (for MDEP approval) detailing what measures will be implemented to conserve water.

Public Water Supply Annual Statistical Reports were obtained from MDEP to understand the magnitude and timing of water withdrawals at Stations 1 and 3 (see Appendix E for Annual Statistics Reports). Shown in Figure 4.2-1 is the average annual withdrawal for 1994-1999. The average annual withdrawal from Stations 1 and 3 collectively is 102.4 MG, which results in an annual average daily demand of 0.28 MGD for the withdrawals from the Saugus River Basin. To understand the seasonality of withdrawals shown in Figure 4.2-2 is the average monthly withdrawals for the period 1994-1999. As anticipated, water usages are greatest in the summer (May-August), lowest in November, and reasonably stable the remainder of the year.

The average maximum daily consumption for the period 1995-99 is 1.33 MGD[14], although the peak factor increased over this period (1999 peak demand was 1.68 MGD). The peak demand occurs during the summer period (2 in June, 2 in July and 1 in August). The average difference between the average daily demand and peak demand from 1995-1999 is approximately 0.67 MGD. The ratio of peak demand relative to average annual demand is 2.03. This ratio suggests that the LCWD peak demand is highly variable relative to the average annual demand. Using the Ipswich Watershed Associations rating of peak factors as a reference, a factor of 2.0 is considered poor.

The LCWD service area does not contain sewer lines, thus residents utilize septic systems for wastewater disposal. Given this, it is assumed that some groundwater recharge occurs via the septic systems. Previous studies conducted for LCWD by CDM estimated the loss of water from the watershed. It should be noted that the study was conducted in 1989; however, it represents the best available information at this juncture. The assumptions in CDM's report include:

- It was assumed that 75% of household water use is returned to the drainage area via septic systems.
- The approximate 1,000 homes located within the Beaverdam Brook drainage area represent 39% of the total number of water services (2,565) in the District.

Using these percentages, CDM estimated the portion of the Phillips Road Wellfield withdrawal, which is returned to the sub-watershed as follows:

[14] Note that this peak demand reflects all four wells, two in the Saugus Basin and two in the Ipswich Basin.

Water Returned to the Sub-watershed (which was withdrawn from the Phillips Road Wellfield= 75% x 39% x (Phillips Road Wellfield Withdrawal)

Since the amount of water returned to the sub-watershed can be computed, the net loss (or water lost from the watershed) can also be estimated. Shown in Figure 4.2-3 is the estimated amount of water returned and lost from the watershed (based on the total volume withdrawn from Stations 1 and 3).

4.3 Wakefield Water Department

The Wakefield Water Department (WWD) provides drinking water to about 25,000 people and it receives approximately 13% of its drinking water from Crystal Lake, with the remainder being imported from the Massachusetts Water Resources Authority (MWRA). Crystal Lake is located in the western portion of the Saugus River Basin (southwestern part of Wakefield) and its watershed encompasses about 500 acres (0.78 square miles) in Wakefield and the neighboring town of Stoneham. There are two discharge points from the lake- to the water supply system or an overflow weir. Discharge from the overflow weir is conveyed to a large culvert, where the river becomes exposed or culverted at various points before discharging into the Mill River, a tributary to the Saugus River.

The lake has a surface area of 0.14 square miles, a total storage volume of 450 MG and a safe yield of 0.68 MG (safe yield is the volume of available water that can be withdrawn safely based on the 1960s drought or the drought of record for the surface water supply). About 5% of the lake and its tributary watershed area are located within the Town of Stoneham.

The WWD has one registered surface water withdrawal from Crystal Lake. They were issued a renewed Registration Statement for water withdrawal on January 1, 1998, effective for ten years. The current registration allows WWD to withdraw an average of 0.48 MGD (175.20 MGY) from Crystal Lake for public water supply. Water supplied by the WWD is collected and eventually treated at the Deer Island Wastewater Treatment Plant, which is located near Boston (outside the Saugus River Basin). Thus, there is a net loss of Crystal Lake water from the Saugus River Basin.

Public Water Supply Annual Statistical Reports were obtained from MDEP to understand the magnitude and timing of water withdrawals from Crystal Lake by WWD (see Appendix F for Annual Statistics Reports). Figure 4.3-1 shows the total annual water use (MGY), average daily water use (MGD), and peak water use (MGD) for the period 1994-1999. As the graph depicts the annual system demand has fluctuated somewhat over the past few years, ranging from 781 MGY in 1994 to 946 MGY in 1996 (these withdrawal volumes include MWRA water). Focusing only on Crystal Lake water use, the annual withdrawal volume has ranged from 88 MGY to 143 MGY, which is well within their allowable withdrawal volume of 175.2 MGY. The majority of the annual water demand (87%) is supplied by MRWA's water supply.

Although there was no maximum daily consumption data reported for 1994 and 1995, the peak demand has consistently occurred in the summer months during 1996-1999 as follows: June (2), July (1), and August (1). The average difference between the average daily demand and peak demand from 1996-1999 is approximately 2.87 MGD. The ratio of peak demand relative to average annual demand is 2.11. This ratio suggests that the WWD peak demand is highly variable relative to the average annual demand. Using the Ipswich River Watershed Association's rating of peak factors as a reference, a factor of 2.0 is considered poor.

The seasonal demand of water was also evaluated to determine if the timing and magnitude of water usage varied throughout the year. Shown in Figure 4.3-2 is a stacked bar graph depicting, by month, the water withdrawals from Crystal Lake and water purchased from MRWA. The average monthly water usage varies seasonally ranging from a low of 51.7 MG in January to 94.7 MG in July. Water use increases during the summer period (June-August) due to watering lawns, car washes, filling swimming pools, etc. Crystal Lake water withdrawals during the 1994 to 1999 period ranged from an average usage of 4.8 MG/month during November to a maximum of 14.4 MG/month in August.

Crystal Lake has a total and available storage capacity of 450 MG and 245 MG, respectively (CDM report- provided by WWD). There is one storage tank with a capacity of 0.495 MG, to pressurize the water distribution system and provide fire flow.

Based on year 2000 data (which was unavailable when this project was first initiated), water use is distributed among residents (71.3% or 861.1 MG annually), commercial (14.0% or 169.6 MG annually), unaccounted for water (9.9% or 120.2 MG annually) and the remaining among schools and day care centers. With a residential service population of approximately 25,000 and annual water usage of 861.1 MG, it equates to an average daily consumption of 94 gpcd, which exceeds the state's water conservation goal of 80 gpcd for residential use.

As noted above, the unaccounted for water in 2000 accounts for 120.2 MG or 9.9% of the WWD's water supply. This value is just within the state's water conservation goal of less than 10 %. The MDEP requires that water suppliers having 15% or greater unaccounted for water indicate the possible reasons.

WWD is in the process of developing a water conservation plan.

4.4 Summary of Water Withdrawals

The purpose of this section is to understand the influence each water withdrawal has on the overall flow regime in the Saugus River. Shown in Table 4.4-1 is the period of available record for each water user.

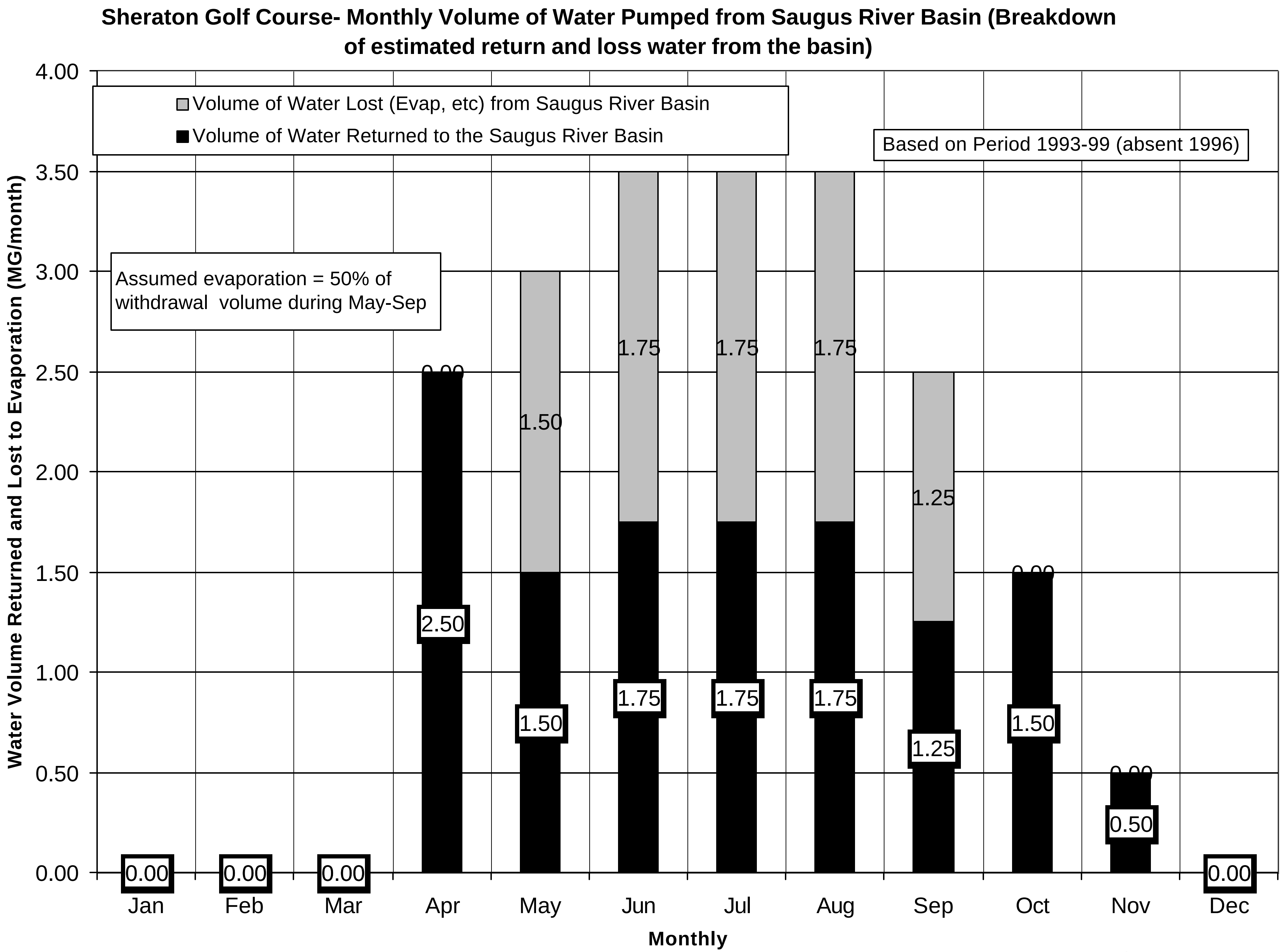
Table 4.4-1: Common Period of Available Record for Each Water User

Source of Water Withdrawal or Water Imported	Period of Available Record
LWSC water withdrawals used for water supply purposes	March 1, 1994-May 31, 2000
Sheraton Golf Course- estimated loss of water from the Saugus River Watershed due to evaporation	January 1, 1994-December, 31, 1999 (except Calendar Year 1996)
LCWD- estimated loss of water due to	January 1, 1994-December 31,1999

evaporation, and other sources	
WWD water withdrawals used for water supply purposes	January 1, 1994-December 31, 1999
Common Period of Record: March 1, 1994-December 31, 1999	

As shown in Table 4.4-1, the common period of record for all water users extends from March 1, 1994 to December 31, 1999. The common period was selected such that comparisons could be drawn between the water users. Using this period, the flow removed from the Saugus River Basin was computed as follows: a) amount of water withdrawn by LWSC, b) amount of water lost to evaporation at the Sheraton Golf Course, c) amount of water lost to evaporation and other sources by LCWD and d) the amount of water WWD withdraws from Crystal Lake.

Shown in Figure 4.4-1 is the annual average flow (MG/year) lost from the following sources in the Saugus River Basin LWSC, Sheraton Golf Course, LCWD and WWD. The majority of water withdrawn or lost from the system is due to LWSC withdrawals (24.9%), followed by WWD (1.5%), LCWD (1.0%)and the Sheraton Golf Course (0.1%). An examination of seasonal trends of water use was also conducted as shown in Figure 4.4-2.



Sheraton Golf Course- Monthly Volume of Water Pumped from Saugus River Basin (Breakdown of estimated return and loss water from the basin)
Volume of Water Lost (Evap, etc) from Saugus River Basin
Volume of Water Returned to the Saugus River Basin
Based on Period 1993-99 (absent 1996)
Assumed evaporation = 50% of withdrawal volume during May-Sep
Water Volume Returned and Lost to Evaporation (MG/month)
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
1.75
1.75
1.75
1.50
1.25
2.50
1.50
1.75
1.75
1.75
1.25
1.50
0.50
0.00
0.00
0.00
0.00
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Monthly

FIGURE 4.1-1


Lynnfield Center Water District: Summary of Water Withdrawals at Stations 1 and 3 from 1994-1999
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
Millions of Gallons
Station 3
Station 1
1999
1998
1997
1996
1995
1994
Average 1994-99
Year

FIGURE 4.2-1

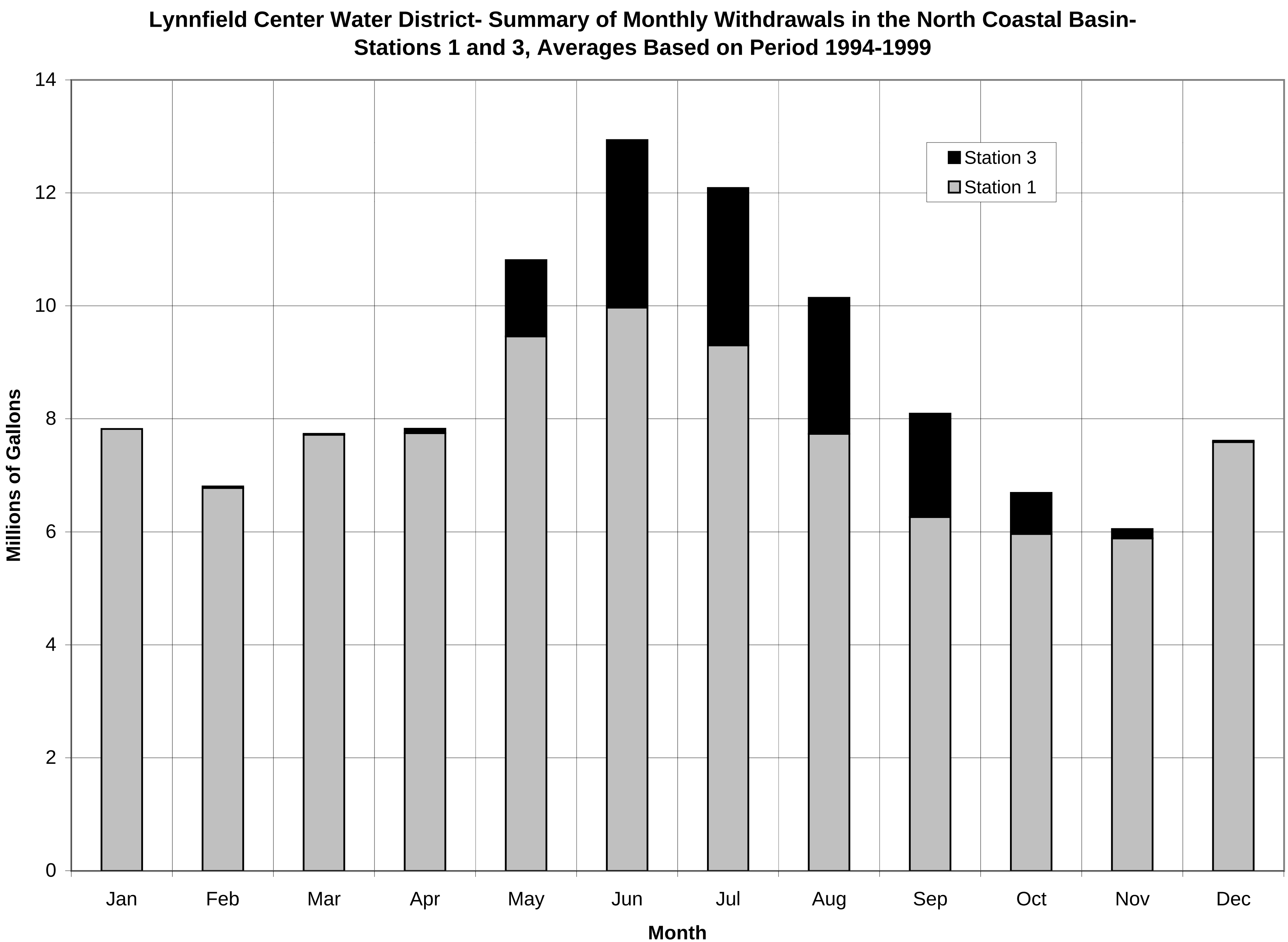

Lynnfield Center Water District- Summary of Monthly Withdrawals in the North Coastal Basin-
Stations 1 and 3, Averages Based on Period 1994-1999
Millions of Gallons
0
2
4
6
8
10
12
14
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Station 3
Station 1

FIGURE 4.2-2

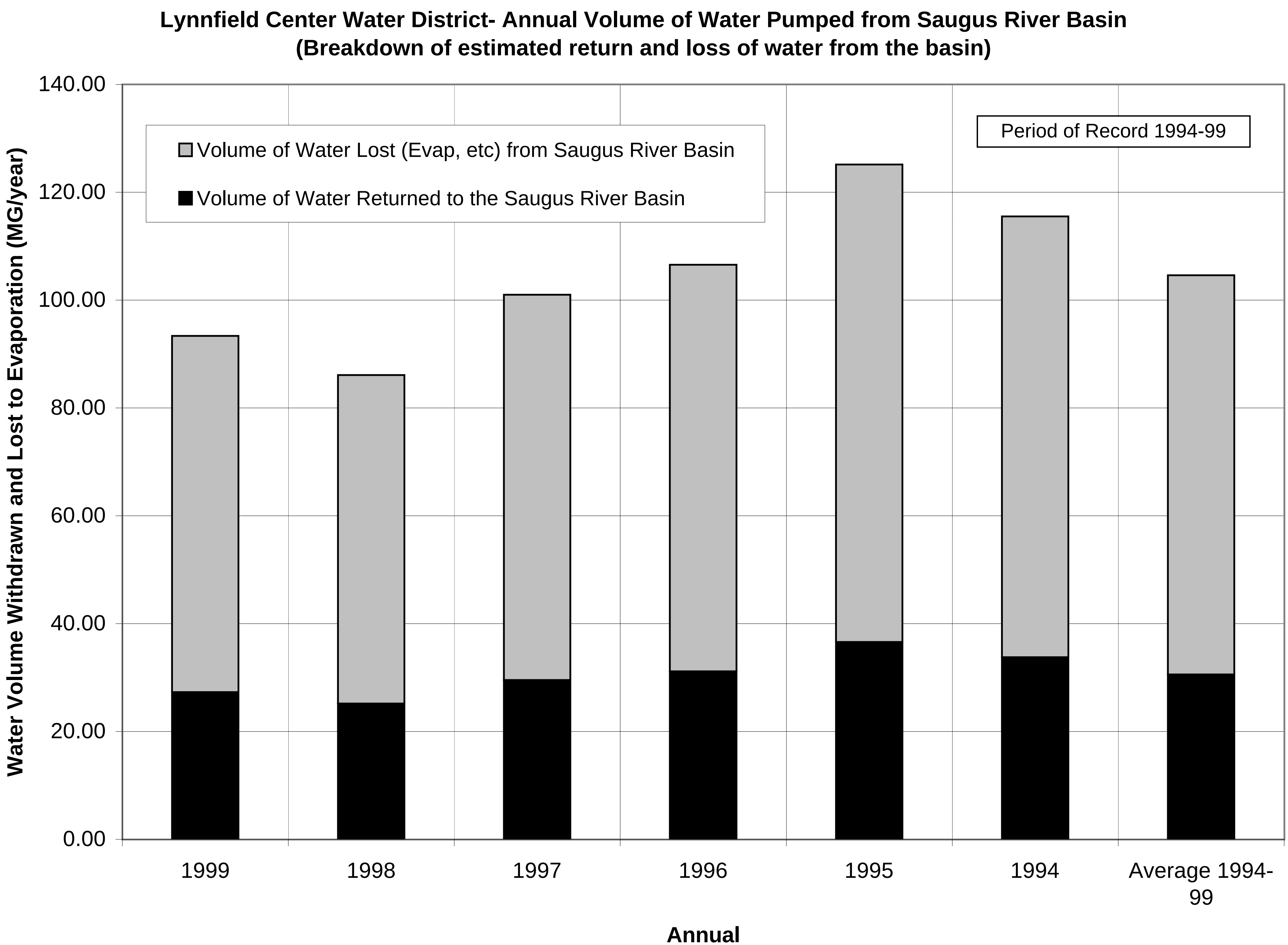
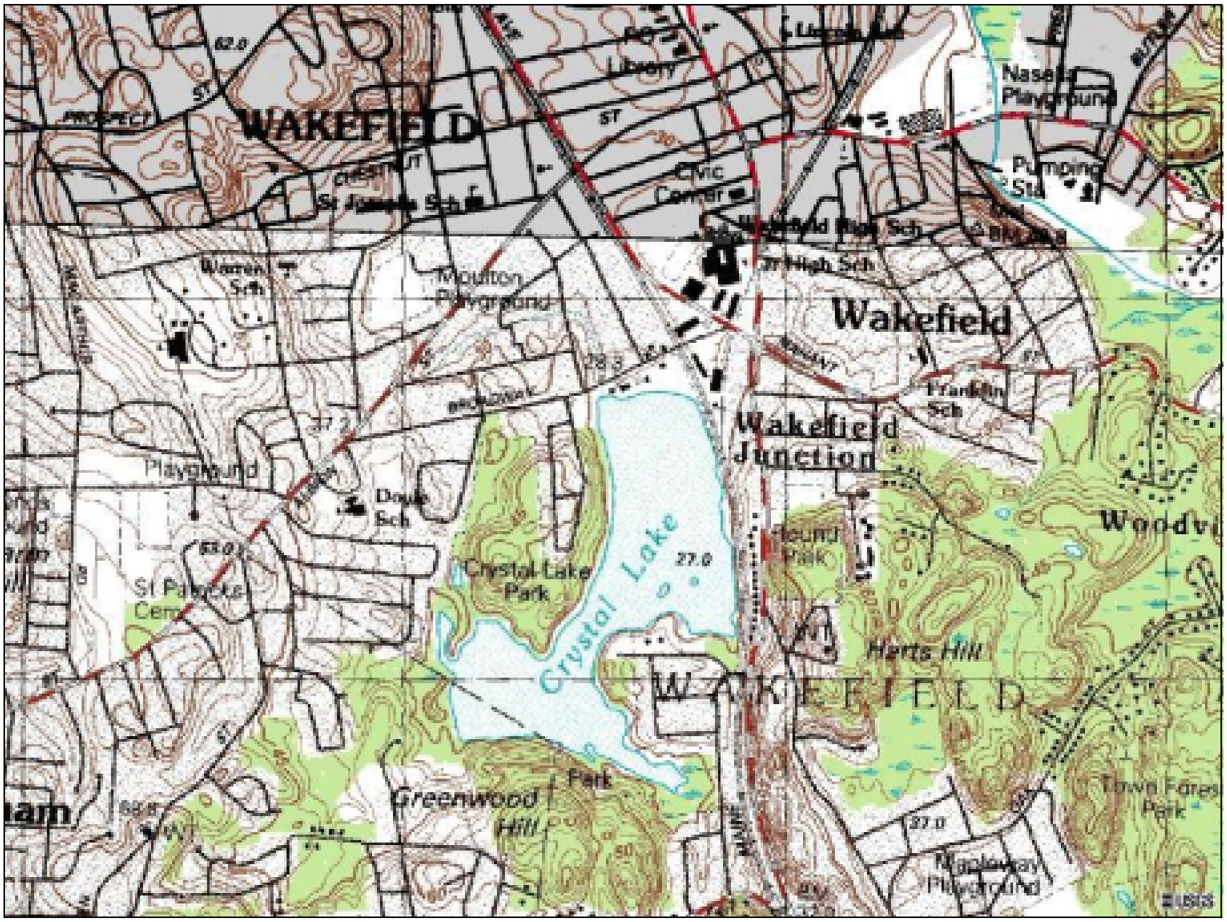

Lynnfield Center Water District- Annual Volume of Water Pumped from Saugus River Basin
(Breakdown of estimated return and loss of water from the basin)
Volume of Water Lost (Evap, etc) from Saugus River Basin
Volume of Water Returned to the Saugus River Basin
Period of Record 1994-99
Water Volume Withdrawn and Lost to Evaporation (MG/year)
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
1999
1998
1997
1996
1995
1994
Average 1994-99
Annual

FIGURE 4.2-3



Topographic Map of Crystal Lake

Picture of Crystal Lake taken from weir outlet looking back at surface water withdrawal. Picture is taken from the northern end of the lake.

Water discharged from the weir travels via culvert under Wakefield and then drains into the Mill River (shown on the far right side of the topographic map).

FIGURE 4.3-1: Topographic Map and Photograph of Crystal Lake

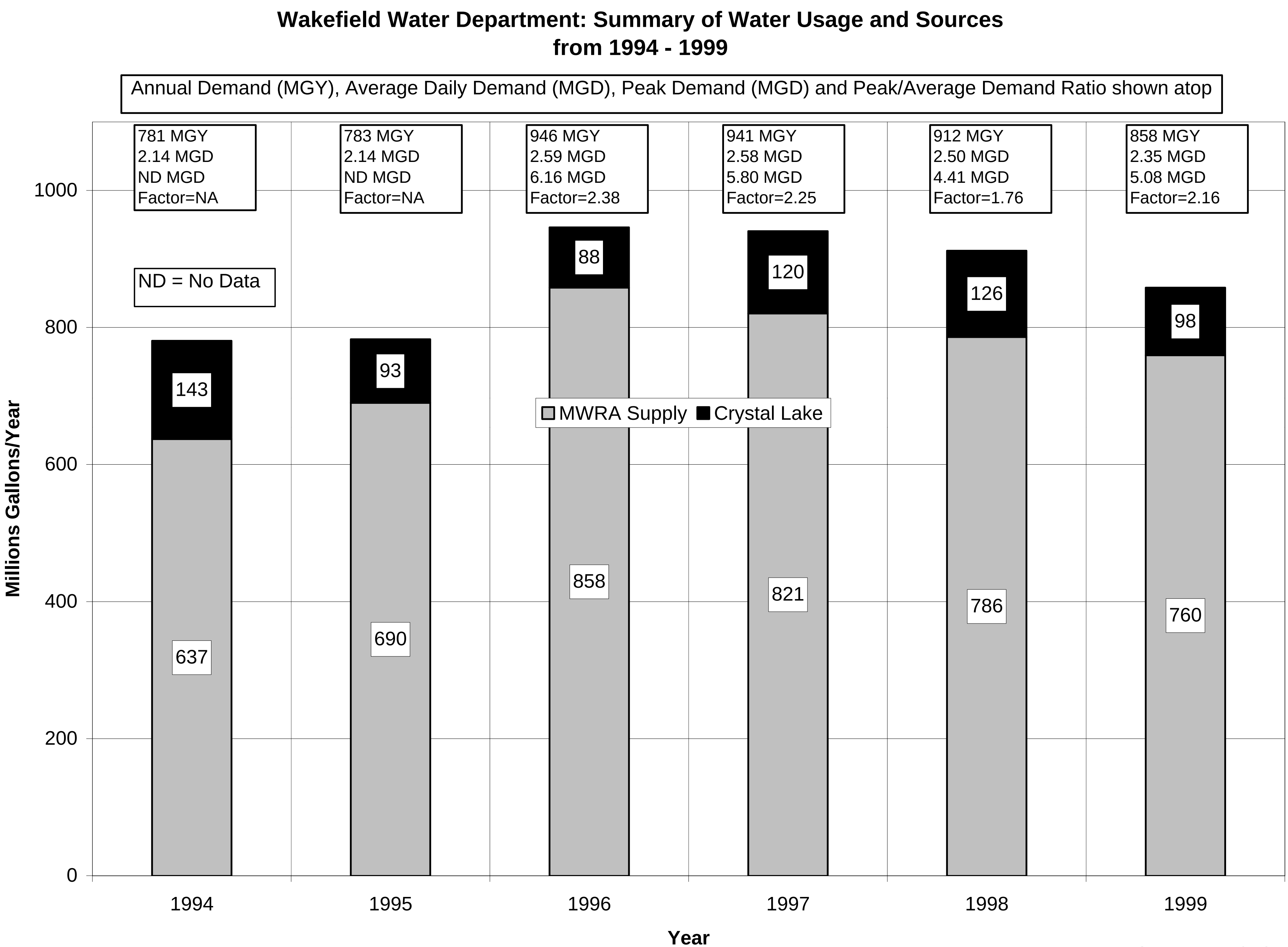

Wakefield Water Department: Summary of Water Usage and Sources
from 1994 - 1999
Annual Demand (MGY), Average Daily Demand (MGD), Peak Demand (MGD) and Peak/Average Demand Ratio shown atop
781 MGY
2.14 MGD
ND MGD
Factor=NA
783 MGY
2.14 MGD
ND MGD
Factor=NA
946 MGY
2.59 MGD
6.16 MGD
Factor=2.38
941 MGY
2.58 MGD
5.80 MGD
Factor=2.25
912 MGY
2.50 MGD
4.41 MGD
Factor=1.76
858 MGY
2.35 MGD
5.08 MGD
Factor=2.16
ND = No Data
MWRA Supply
Crystal Lake
143
637
93
690
88
858
120
821
126
786
98
760
Millions Gallons/Year
0
200
400
600
800
1000
1994
1995
1996
1997
1998
1999
Year

FIGURE 4.3-2

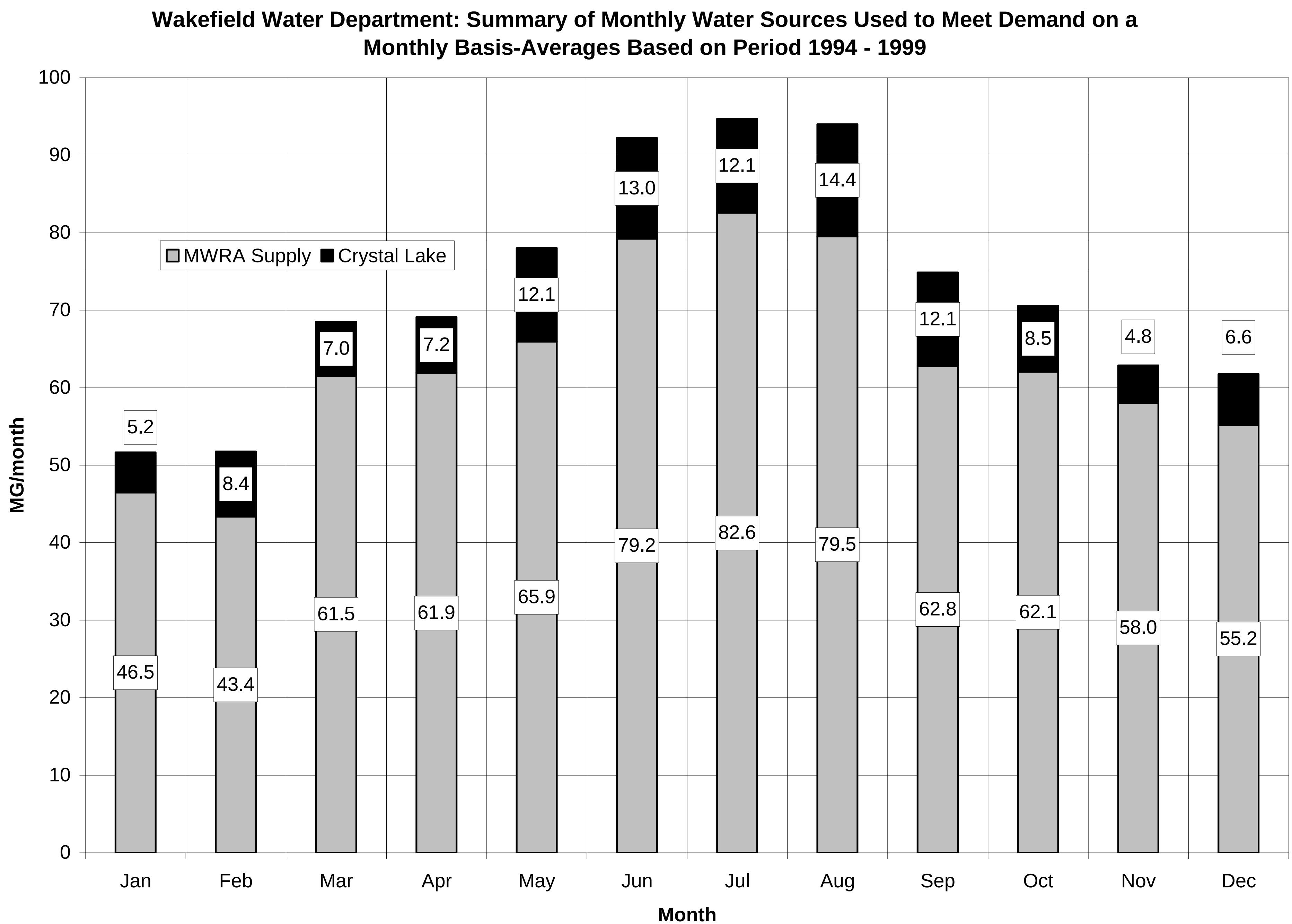
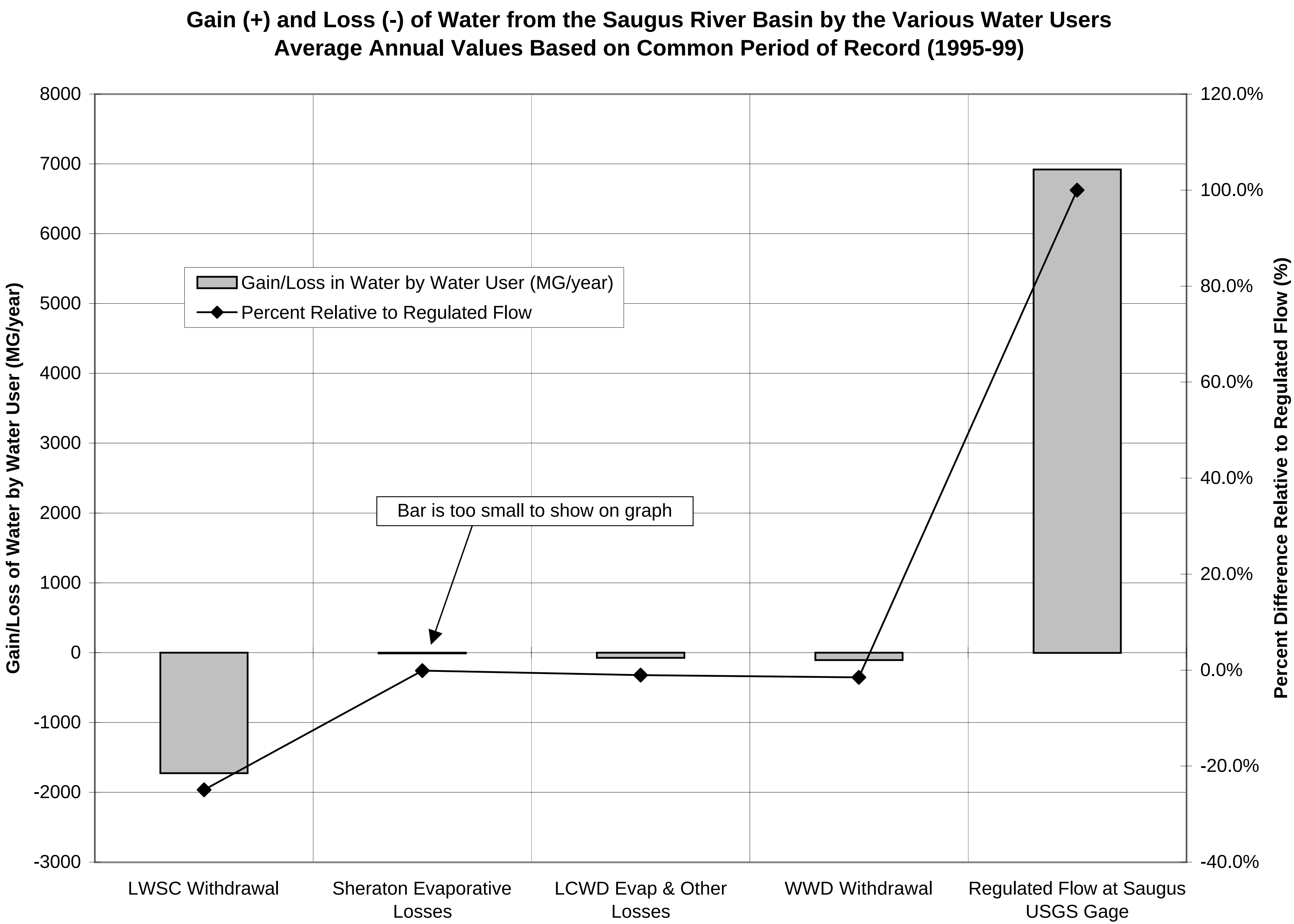

Wakefield Water Department: Summary of Monthly Water Sources Used to Meet Demand on a Monthly Basis-Averages Based on Period 1994 - 1999
MWRA Supply
Crystal Lake
MG/month
Month
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
46.5
5.2
43.4
8.4
61.5
7.0
61.9
7.2
65.9
12.1
79.2
13.0
82.6
12.1
79.5
14.4
62.8
12.1
62.1
8.5
58.0
4.8
55.2
6.6
0
10
20
30
40
50
60
70
80
90
100

FIGURE 4.3-3



Gain (+) and Loss (-) of Water from the Saugus River Basin by the Various Water Users
Average Annual Values Based on Common Period of Record (1995-99)
8000
7000
6000
5000
4000
3000
2000
1000
0
-1000
-2000
-3000
120.0%
100.0%
80.0%
60.0%
40.0%
20.0%
0.0%
-20.0%
-40.0%
Gain/Loss of Water by Water User (MG/year)
Percent Difference Relative to Regulated Flow (%)
Gain/Loss in Water by Water User (MG/year)
Percent Relative to Regulated Flow
Bar is too small to show on graph
LWSC Withdrawal
Sheraton Evaporative Losses
LCWD Evap & Other Losses
WWD Withdrawal
Regulated Flow at Saugus USGS Gage

FIGURE 4.4-1

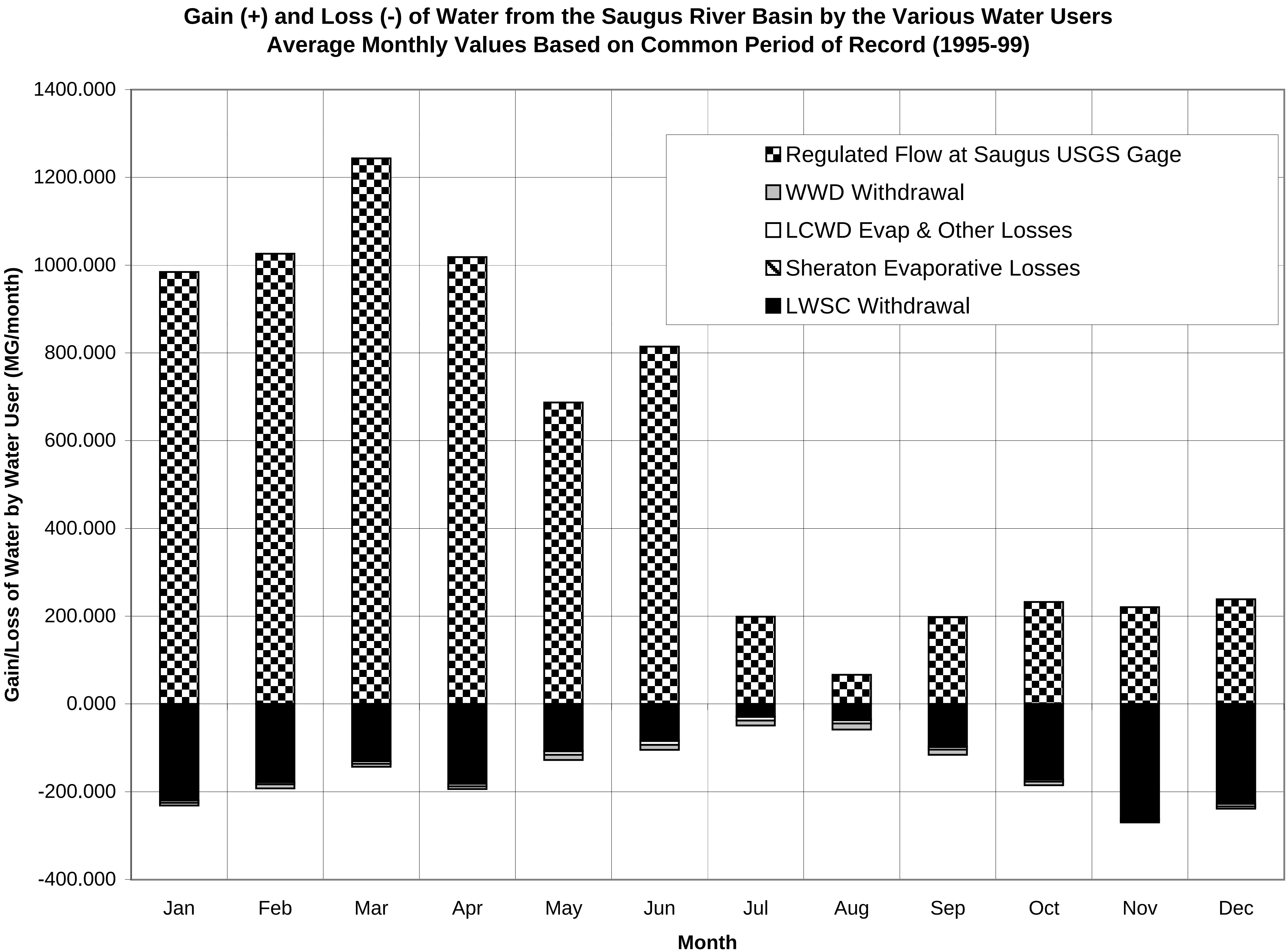

Gain (+) and Loss (-) of Water from the Saugus River Basin by the Various Water Users
Average Monthly Values Based on Common Period of Record (1995-99)
Regulated Flow at Saugus USGS Gage
WWD Withdrawal
LCWD Evap & Other Losses
Sheraton Evaporative Losses
LWSC Withdrawal
Gain/Loss of Water by Water User (MG/month)
1400.000
1200.000
1000.000
800.000
600.000
400.000
200.000
0.000
-200.000
-400.000
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

FIGURE 4.4-2

5.0 Hydrology

5.1 Sources of Flow Regulation

The Saugus River is heavily regulated from several sources including:

- The LWSC diverts water from the Saugus River to Hawkes Pond for water supply purposes. LWSC also controls the discharge below the Diversion Dam, when Reedy Meadows elevation is below the dam spillway crest (controlled release through the dam gate).
- LWSC also operates four reservoirs (Hawkes Pond, Walden Pond, Birch Pond, and Breeds Pond) for water supply purposes. Runoff from the surrounding watersheds is used to meet water supply demands. Except for outside use or spillage at the dams, most of the water is not returned to the Saugus River Basin, rather it is sent to the Lynn Harbor Wastewater Treatment Plant.
- Lynnfield Center Water District (LCWD) maintains three wells in the Beaverdam Brook Watershed to support residential needs in the area. The average annual withdraw, for the period 1995-99, is 102 MGY (0.28 MGD). Water is lost from the system due to evaporation and other sources.
- The Wakefield Water Department (WWD) withdraws water from Crystal Lake for water supply needs. The average annual withdraw from Crystal Lake, for the period 1994-99, is 111.4 MG. Except for outside water use, most of the water is not returned to the Saugus River Basin, rather it is sent to the Deer Island Wastewater Treatment Plan.
- The Sheraton Colonial Country Club withdraws water from an unnamed pond within the Saugus River Watershed for greens watering. The average annual withdraw reported for the period 1993-99 (absent 1996) is 20.5 MG (0.056 MGD). Water is lost from the system due to evaporation.

Other sources of regulation include:

- Lake Quannapowitt is lowered in the fall/winter, and refilled in the spring, thus some seasonal regulation occurs.
- Historically some seasonal regulation of Pillings Pond occurred (1-2 foot drawdown in the fall/winter).
- Crystal Lake is operated as a reservoir to meet Wakefield Water Department water supply needs.
- The watershed is urbanized. Storm runoff from impervious areas is conveyed primarily through culverts and drains, which impacts the timing, rate and magnitude of runoff. In some instances storm drains and road culverts may become clogged, resulting in backwatered areas.
- There are most likely numerous other well withdrawals in the Saugus River Watershed, however, the withdrawal volumes are less than 100,000 gallon/day, thus no reporting is required. The cumulative impact of these withdrawals is unknown (and is beyond the scope of this study).

The regulated hydrology can be quantified using flow data from the USGS gage (Gage No. 0110234) at the Ironworks, which is upstream of the tidal influence. One of the goals of this study is to estimate the hydrology without regulation, which is somewhat difficult to quantify due to the numerous sources of regulation. As noted above, LWSC controls the majority of regulation in the watershed. Data on their operations is available, specifically estimated Saugus River withdrawals. Quantitative data is also available on the LCWD, WWD and Sheraton Golf Course (described in Sections 3 and 4). As described below, the hydrology under unregulated conditions was quantified. It should be clearly noted that the determination of unregulated conditions does not account for:

- Regulation resulting from water level operation at Lake Quannapowitt, Pillings Pond and Crystal Lake. By lowering lake/pond levels prior to the spring runoff, these facilities serve to reduce peak flows downstream during the high runoff period. In summary, with these facilities in place, the magnitude of spring runoff is reduced below the projects, and the timing of runoff is attenuated.
- The analysis assumes that land use in the watershed is representative of today's condition. Increased development has resulted in more impervious surfaces in the watershed. Thus, the magnitude and timing of runoff has changed. Flow data prior to urbanization is not available and development of a model to estimate Pilgrim flow is beyond the scope of this study.
- There are occasions where LWSC "spills" or releases water when reservoir levels are exceedingly high. To prevent overtopping, LWSC will open gates and release water that eventually flows back into the Saugus River above the USGS gage. This occurs infrequently, and only under extremely high flow conditions such as in October 1996. The analysis assumes that all water withdrawn at the Diversion Dam is not returned to the Saugus River; rather it is discharged as wastewater outside of the basin. However, under extreme high flow conditions, LWSC may release water at the reservoirs, returning water to the Saugus River. Because spill events are rare, they were not included in the analysis.
- The analysis does not account for runoff around the four LWSC storage reservoirs, which comprise 5.36 square miles of the watershed (recall the drainage area at the Saugus River USGS gage is 23.3 square miles). Without the storage reservoirs in place, the magnitude of runoff observed at the USGS gage would be higher. Insufficient data is available to quantify this source of regulation.

5.2 Methodology for Estimating LWSC Saugus River Withdrawals

To estimate the Saugus River hydrology without Saugus River withdrawals an analysis of data records maintained by LWSC was conducted. LWSC has collected the following data on daily log sheets for the period January 1, 1988-present.

- Canal sluice gate opening in inches (this is shown as "Saugus Canal Gate" on the log sheet)
- Canal Water Surface Elevation in inches (this is the depth to the water surface as measured from a fixed reference point- from the top of the wall to the water)
- Lower Reedy Meadows Water Surface Elevation in inches (this is the depth to the water surface or headpond elevation as measured from a fixed reference point- known as dam

measurement (in inches) in Table 5.2-1. Note the measure downs are now referenced to a common datum. The datum at the Diversion Dam is elevation 79.0 feet, whereas the datum at the Canal is elevation 80.09 feet).

It should be noted that the reference points used for measure downs to the water surface in the headpond and canal were tied together by survey (LWSC kindly offered their services to complete the survey).

Given the Reedy Meadows headpond elevation, canal tailwater elevation, and canal sluice gate opening on a daily basis for the past 12 years, the daily water withdrawals could be estimated if a rating curve or table were available. The difference between the headpond and canal water surface elevations represents the head across the canal sluice gate.

LWSC has developed a table relating canal gate discharge as a function of the headpond elevation and canal gate opening. LWSC estimates canal flows indirectly by monitoring Hawkes Pond elevations, pumping records, and estimated Hawkes Brook inflow. According to LWSC the table has been updated and refined over the years.

A two-step approach was used to estimate canal discharges. First, the headpond elevation was subtracted from the canal elevation to determine if flow was moving backwards (from Hawkes Pond to the Saugus River). When the canal elevation was greater than the headpond elevation, the discharge through the canal gate was zero. When the headpond elevation was greater than the canal elevation, the canal discharge was estimated based on Table 5.2-1. Note that odd canal gate openings (3”, 5”, etc) were not provided and thus were linearly interpolated between even canal gate openings.

Table 5.2-1: LWSC Relationship between Dam Measurement/Canal Gate Opening and Canal Discharge (in MGD)

Dam Measurement (measure down in inches) or Elevation (datum is 79.0 ft)	Canal Gate Opening						
	2”	4”	6”	8”	10”	12”	13”
26-30” or Elevation 76.8-76.5’	7.5	9.0	10.5	12.0	13.5	15.0	16.5
31-34” or Elevation 76.4-76.2’	6.5	8.0	9.5	11.0	12.5	14.0	15.5
35-38” or Elevation 76.1-75.8’	5.5	7.0	8.5	10.0	11.5	13.0	14.5
39-42” or Elevation 75.8-75.5	4.5	6.0	7.5	9.0	10.5	12.0	13.5
43-46” or Elevation 75.4-75.2	3.5	5.0	6.5	8.0	9.5	11.0	12.5
47-50” or Elevation 75.1-74.8	2.5	4.0	5.5	7.0	8.5	10.0	11.5

To confirm Table 5.2-1, flow metering was conducted in the canal under different canal gate openings and dam measurements.

On August 25, 2000, Gomez and Sullivan measured the canal flow under seven gate settings, which were determined based on historical gate data. Shown in Figure 5.2-1 is a canal gate opening duration curve, which describes the range of gate settings based on 12 years of data. Historically, gate settings are between 2 and 16 inches. LWSC has indicated that gate settings above 16 inches do not occur as they have difficulty closing the gate.

The dam measurements, at the time of fieldwork, were within the 39-42" range. Flow metering was conducted at canal gate openings of 2, 4, 6, 8, 10, and 13 inches. Shown in Table 5.2-2 is a comparison between the measured flow and that provided from Table 5.2-1.

Table 5.2-2 Comparison of Measured versus Estimated Canal Flows

Canal Gate Opening	Flow Based on Table 5.2-1 (in MGD)	Measured Flow in Canal (in MGD)	Difference (in MGD)
2 inches	4.5	3.2	+1.3
4 inches	6.0	6.1	-0.1
6 inches	7.5	9.0	-1.5
8 inches	9.0	10.2	-1.2
10 inches	10.5	11.4	-0.9
13 inches	13.5	11.9	+1.6

As Table 5.2-2 shows, the difference between the measured flow and that estimated from Table 5.2-1 is greatest at the higher gate openings. The flow at each gate setting was made at the 39-42" dam measurement only. No flow metering was conducted under different dam elevations, thus it is unknown if Table 5.2-1 is accurate for other elevations. Given that the number of flow measurements is limited (more points in Table 5.2-2 would be more ideal), there is no way to extrapolate the measured data to cover the range of dam elevations. Given this, we are limited at using Table 5.2-1. Future updating of this analysis could take place since LWSC is currently in the process of installing a meter in the canal. The meter will measure flow conveyed to Hawkes Pond. A more refined table, similar to Table 5.2-1 could be developed at a later date.

In summary, for purposes of this analysis, Table 5.2-1 will be used to compute LWSC withdrawals as it represents the best available data. A spreadsheet was developed, which required as inputs the gate setting, dam elevation and canal elevation. The output or discharges was then computed based on Table 5.2-1. The computed flow and that recorded by LWSC (from the Annual Reports) compared well as summarized in Table 5.2-3.

Table 5.2-3. Comparison of Computed and Reported Annual Withdrawals by the LWSC

Year	Computed Yearly Withdraw MG/year	Reported Yearly Withdraw MG/year	Percent Difference (%)
1995	1,642	1,684	2.5%
1996	1,333	1,590	16.1%
1997	1,488	1,532	2.8%
1998	1,846	1,961	5.9%
1999	1,848	1,858	0.5%

As Table 5.2-3 shows, the computed and reported annual withdrawals are close, except for 1996.

Without the LWSC withdrawal, that volume of water would eventually be passed down the Saugus River and captured at the USGS gage. Therefore, to compute the unregulated flow at the USGS gage, the computed daily withdrawals were added to the measured flows at the USGS gage.

5.3 Sheraton Golf Course, Lynnfield Center Water District, Wakefield Water Department

As noted above the Sheraton Golf Course withdrawals water from an unnamed pond for greens watering. MDEM has approximated that 50% of the water used for greens watering during the period May-September is lost from the system due to evaporation and evapotranspiration. Without green watering, there would be less evaporation and evapotranspiration. Hence, when computing the unregulated flow, the water lost to evaporation is added to the Saugus River USGS gage.

The amount of water lost to evaporation and other sources from the LCWD was also computed as described in Section 4.2. Lastly, the WWD withdraws water from Crystal Lake that is not returned to the Saugus Basin. Again, when computing the unregulated flow, the water lost from the system is added to the Saugus River USGS gage.

5.4 Period of Record and Time Step for Analysis

The period of record and time step of available data is summarized in Table 5.4-1. In the far right hand column of Table 5.4-1 is a description of the steps needed to convert data to a common time step and period of record. In the end, a daily time step was developed for the period 3/1/94-12/31/99.

Table 5.4-1: Common Period of Record and Time Step for Each Water User

Source of Water Withdrawal or Water Imported	Period of Available Record	Time Step	Period of Record Used in Analysis and suggested modifications to available data
LWSC water withdrawals used for water supply purposes	3/1/94-5/31/2000	Daily	3/1/94-12/31/99 No changes to time step
Sheraton Golf Course- estimated loss of water from the Saugus River Watershed due to evaporation	1/1/1994-12/31/99 (except Calendar Year 1996)	Monthly	3/1/94-12/31/99 1996 data is missing, however, Sheraton has reported the exact same withdrawals each year. Use the same data for 1996. Convert monthly evaporation losses to daily
LCWD- estimated loss of water due to evaporation, and other sources	1/1/94-12/31/99	Monthly	3/1/94-12/31/99 Convert monthly evaporation losses to daily
WWD water withdrawals used for water supply purposes	1/1/94-12/31/99	Monthly	3/1/94-12/31/99 Convert monthly data to daily
Common Period of Record Used in Analysis: March 1, 1994-December 31, 1999, Daily Data			

The unregulated flow at the Saugus USGS gage was subsequently calculated using the following formula:

Unregulated Flow at USGS Gage= Regulated Flow measured at USGS Gage + Evaporative Losses at Sheraton Golf Course + Evaporative Losses at LCWD + LWSC Water Withdrawals + WWD Water Withdrawals

5.5 Flow and Aquatic Habitat

The purpose for quantifying the Saugus flow regime under regulated and unregulated flow conditions is to determine how regulation impacts the magnitude, timing, duration and rate of flow change in the Saugus River. These hydrologic variables (magnitude, timing, duration, rate of change) have an impact on the quality and quantity of fish habitat present in the Saugus River. Magnitude refers to the range of flows experienced in the watershed, which directly impacts the wetted area and aquatic (fish) habitat volume in the river. Depending on the life stage and fish species present in the river, the amount of habitat will vary as the magnitude of flow varies.

The timing of flows (seasonally) is also important as it influences whether certain fish life-cycle requirements are achieved. For example, there are various flow requirements for spawning/incubation, fry, juvenile and adult fish, which vary throughout the year. If flows are too high or low during a specific life-cycle period, it could be detrimental to the specific life stage and species of fish.

Rate of change (how quickly flow changes over a short time period) is particularly relevant to this project as Diversion Dam gate changes can occur over minutes. Changing the dam gate from an open to closed position may result in stranding of fish and other organisms along the water's edge or in ponded depressions. Macroinvertebrates, which fish utilize as a food source, are an immobile species that cannot respond quickly to changing flow regimes. Macroinvertebrates could become established along the river's edge below the Diversion Dam when the gate was open and flow is continuous. An abrupt reduction or closing of the gate would result in stranding these species.

By "re-creating" the unregulated flow regime, the magnitude, timing, duration and rate of flow changes can be estimated absent Saugus River water withdrawals. Each of these hydrologic variables is quantified under regulated and unregulated flow conditions as described below. To limit the number of figures, and to allow for easy comparisons, regulated and unregulated flow conditions are shown on the same figures.

5.6 Unregulated and Regulated Hydrology

5.6.1 Background

Before reviewing the hydrology findings, it should be noted that the Massachusetts USGS has developed a program called "Streamstats" that is designed to estimate low flows at any stream location in a watershed. The program provides stream statistics based on an unregulated environment at any stream location in Massachusetts (MA). MA USGS was contacted to determine if the Streamstats program could be applied to the Saugus River. We were informed that the regression variables used to develop flow statistics were not developed for the North

Coastal Watershed (which includes the Saugus), because there was inadequate correlation. Therefore, no further evaluation using the Streamstats program was conducted.

5.6.2 Magnitude and Timing

Using the existing USGS gage to reflect regulated conditions and the "re-created" USGS gage to reflect unregulated conditions, the magnitude and timing of flows were quantified. The USGS gage has been active since March 1, 1994 and has a drainage area of 23.3 mi^2. It should be noted that flow data from October 1, 1999 to December 31, 1999 is considered provisional by the USGS at this juncture.

Using the unregulated and regulated flow data mean monthly flows were computed for the period of record as shown in Figure 5.6.2-1. The difference between the regulated and unregulated mean monthly flow represents the combined effects of regulation (LWSC, LCWD, WWD, Sheraton). Also shown in Figure 5.6.2-1 is the percent difference between the regulated and unregulated flow. The greatest percent difference occurs in August (3.3 cfs, 46.3%) and November (13.3 cfs, 35.3%). Although the August computed difference is small (3.3 cfs), it represents a large percentage of the overall flow (46.3%). Given that flows are already low during the summer an additional 3.3 cfs loss is considered significant. The lack of maintaining adequate summer flows can impact aquatic resources, and water quality. Water temperatures can rise significantly with limited flow. During November and December, LWSC is refilling their water storage system, hence the large difference in flow.

Another method for depicting the magnitude and timing of flows is an annual hydrograph. Shown in Figure 5.6.2-2 is the average annual hydrograph, which was developed by averaging all six years worth of flow data for each day. For example, the flow on March 1, 1994, March 1, 1995 through March 1, 1999 was averaged to yield one point on the hydrograph. The same procedure was conducted for all 365 days in the year.

Further evaluation of the summer and November flows were conducted. Shown in Figures 5.6.2-3 and 5.6.2-4 are hydrographs for the period July 24-August 16 and November 1-30, respectively (these graphs are essentially the same as Figure 5.6.2-2 except the x-axis is enlarged). The percent difference between the regulated and unregulated flow is also shown on the graphs. Again, there is a sizeable difference (magnitude and percentage) between the regulated and unregulated flow. During portions of the summer and November period, regulated flow is only about half of the calculated unregulated flow.

Overall, the sources of regulation do not significantly impact the magnitude of extremely high flow events observed in the Saugus River Basin. Shown in Figure 5.6.2-5 is a hydrograph for the October /November 1996 flood, which shows little difference between the regulated and unregulated flow (the lines are virtually the same on Figure 5.6.2-5). The LWSC, the largest source of regulation, is limited by how water much can be conveyed in the diversion canal to Hawkes Pond. During a high flow event, the amount of water diverted would be far less than the total flow at the Diversion Dam. In fact during the 1996 flood, LWSC was not diverting any flow due to high water levels at Hawkes Pond.

The sources of regulation do impact the magnitude of average and low flows during various times of year, particularly the summer and fall. With respect to timing or seasonal distribution of flows, regulation has also impacted the natural distribution. For example, refilling of LWSC reservoirs in the fall, has changed the natural timing of the runoff portions of streamflow during these periods.

Low and flood flow frequency statistics were not generated since the period of record for the USGS gage is so short (6 years of data). For example, to calculate the low flow statistic, 7Q10, a minimum of 10 years of data is necessary. Similarly, flood frequency analyses typically require at least 25 years of record.

5.6.3 Flow Duration

Annual and monthly flow duration curves were developed to depict the percentage of time flows are present in the Saugus River under regulated and unregulated conditions. Annual and monthly flow duration curves are shown in Figures 5.6.3-1 through 5.6.3-13.

5.6.4 Rate of Change

The USGS was contacted to obtain hourly flow data at the Ironworks gage for calendar year 1999. The hourly flow data was obtained to observe how the Diversion Dam gate changes influence the rate of flow change approximately 5 miles downstream at the USGS gage. The rate of change is obviously more abrupt closer to the gate and dissipates downstream, as runoff from the intermittent watershed flows into the Saugus River. Diversion Dam gate openings for 1999 were reviewed to identify a period when the gate opening changed from an open to closed position to determine how flow rates change downstream. In reviewing the record, during April 14, 1999 the Diversion Dam gate was open 5 inches and then closed on April 15, 1999. The time when the gate was closed on the April 15 is not known. Shown in Figure 5.6.4-1 is an hourly hydrograph for the period April 14, 1999 at 1:00 am to April 18, 1999 at midnight. Figure 5.6.4-1 also shows the daily precipitation totals, which explain why the hydrograph increases after the gate is closed on April 15. As the figure shows, there is a lag on when the gate is closed to having the flow rate decrease at the USGS gage. The flow drops distinctly from approximately 18.3 cfs on April 15 (9:00 pm) to 12.2 cfs on April 16 (6:00 pm), after which the flow increases most likely due to precipitation runoff. As noted above, the flow rate will drop much faster in the Saugus River just below the gate and fish/macroinvertebrates will have less time to respond to changing flow conditions. As noted later, the Saugus River Watershed Council (SRWC) has observed fish stranding below the Diversion Dam.

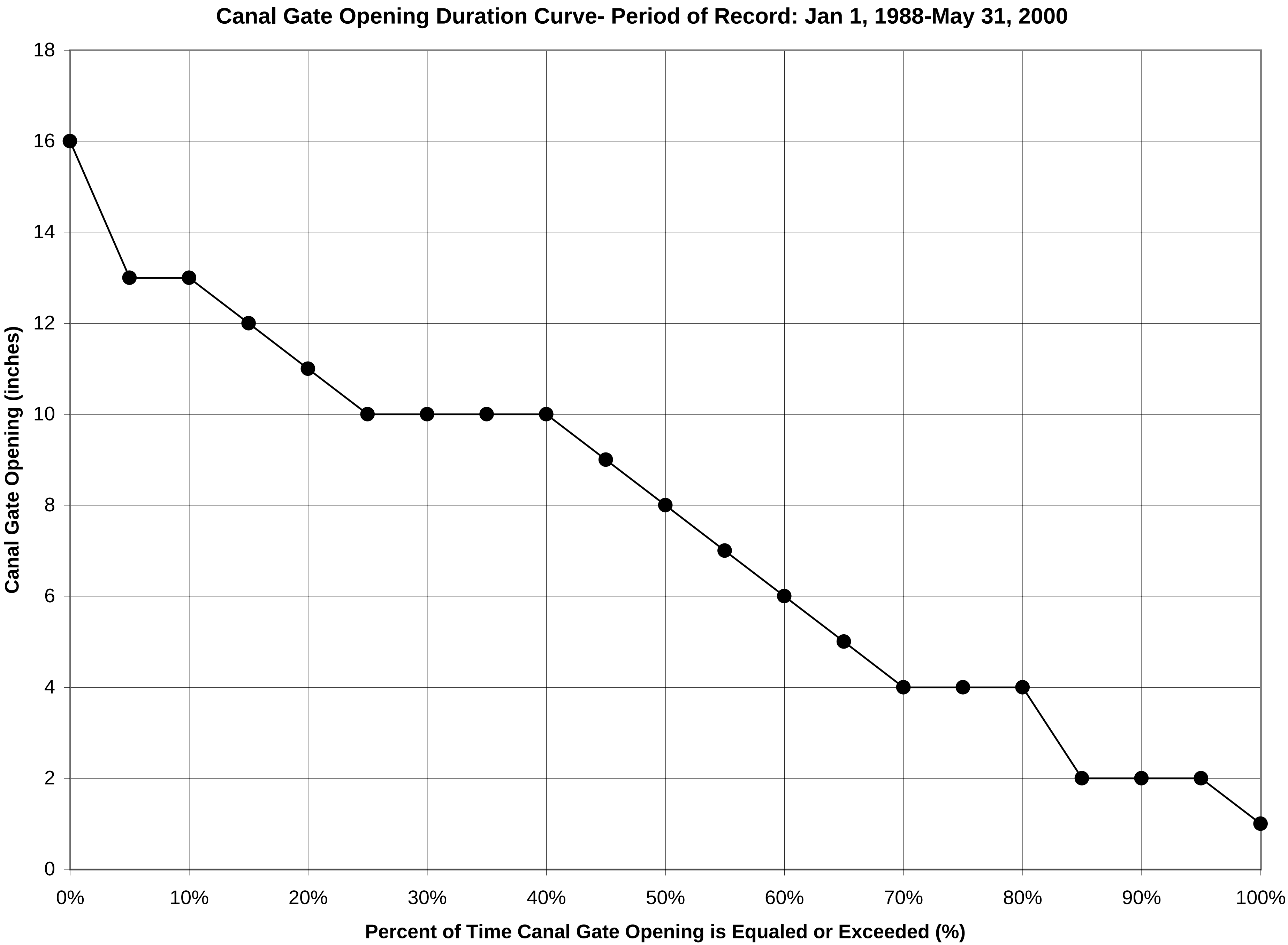

Canal Gate Opening Duration Curve- Period of Record: Jan 1, 1988-May 31, 2000
Canal Gate Opening (inches)
0
2
4
6
8
10
12
14
16
18
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Percent of Time Canal Gate Opening is Equaled or Exceeded (%)

FIGURE 5.2-1

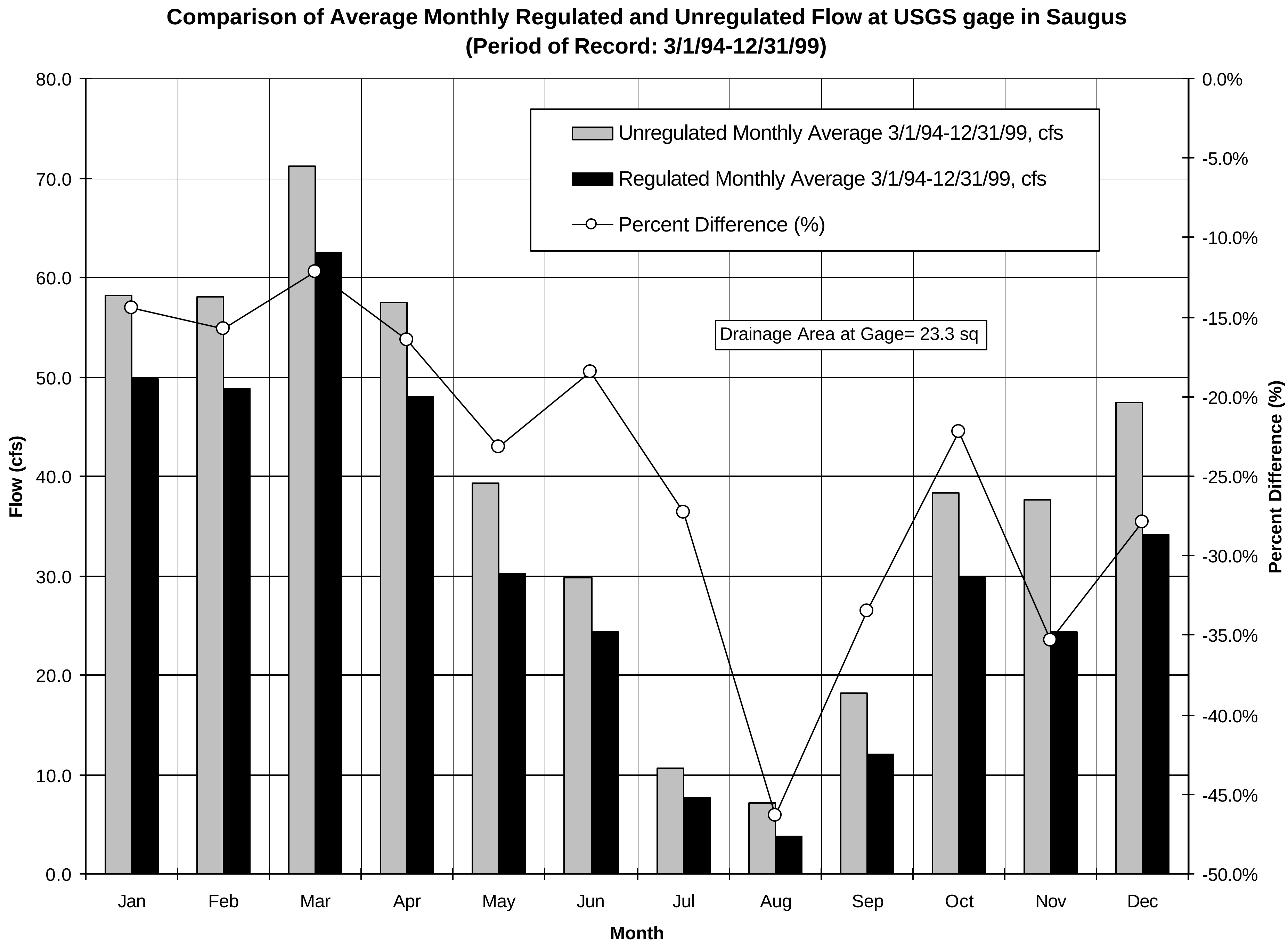

Comparison of Average Monthly Regulated and Unregulated Flow at USGS gage in Saugus
(Period of Record: 3/1/94-12/31/99)
Unregulated Monthly Average 3/1/94-12/31/99, cfs
Regulated Monthly Average 3/1/94-12/31/99, cfs
Percent Difference (%)
Drainage Area at Gage= 23.3 sq
Flow (cfs)
Percent Difference (%)
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.0%
-5.0%
-10.0%
-15.0%
-20.0%
-25.0%
-30.0%
-35.0%
-40.0%
-45.0%
-50.0%
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

FIGURE 5.6.2-1

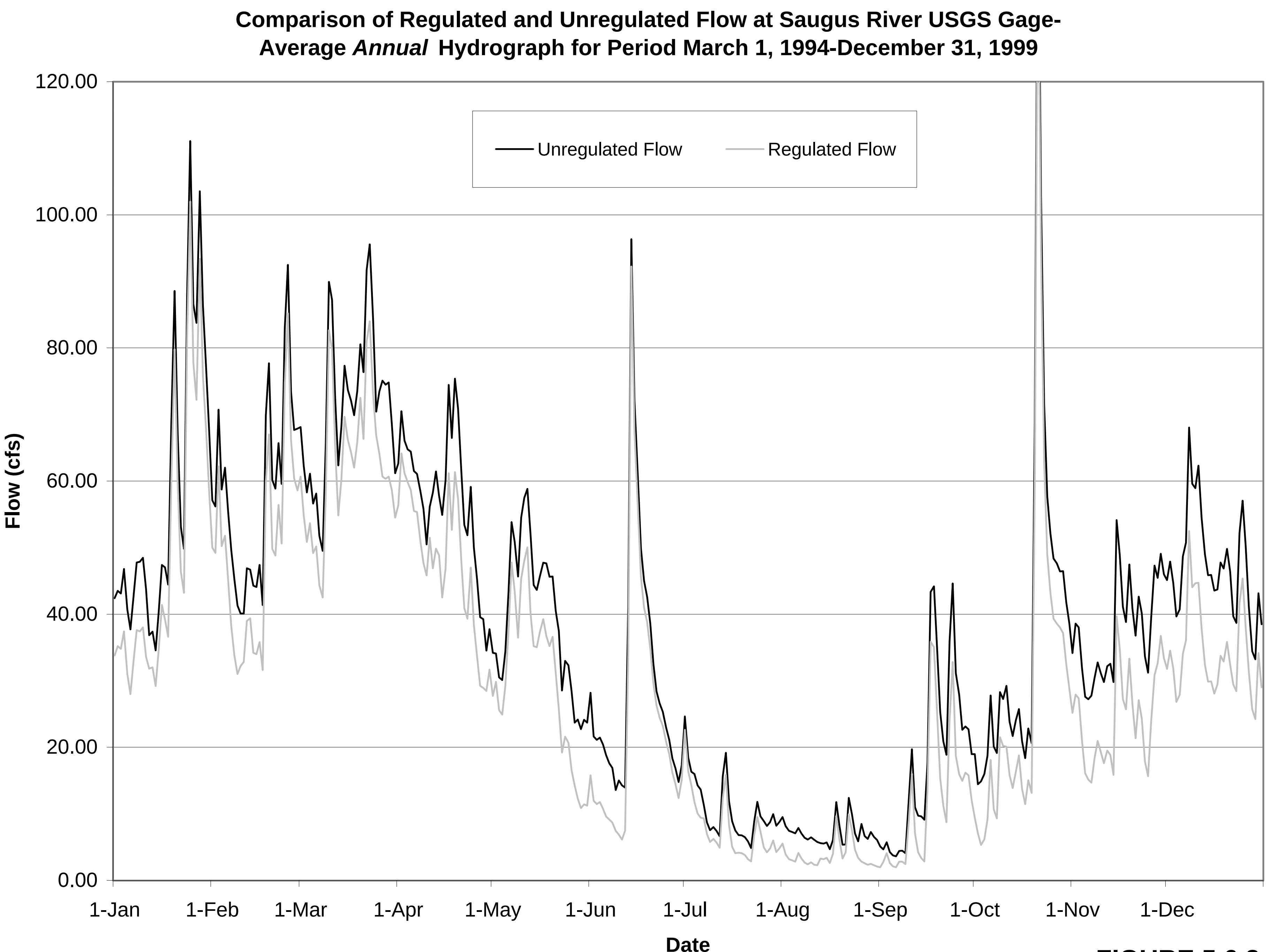

Comparison of Regulated and Unregulated Flow at Saugus River USGS Gage-
Average *Annual* Hydrograph for Period March 1, 1994-December 31, 1999
Unregulated Flow
Regulated Flow
Flow (cfs)
120.00
100.00
80.00
60.00
40.00
20.00
0.00
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
Date

FIGURE 5.6.2-2

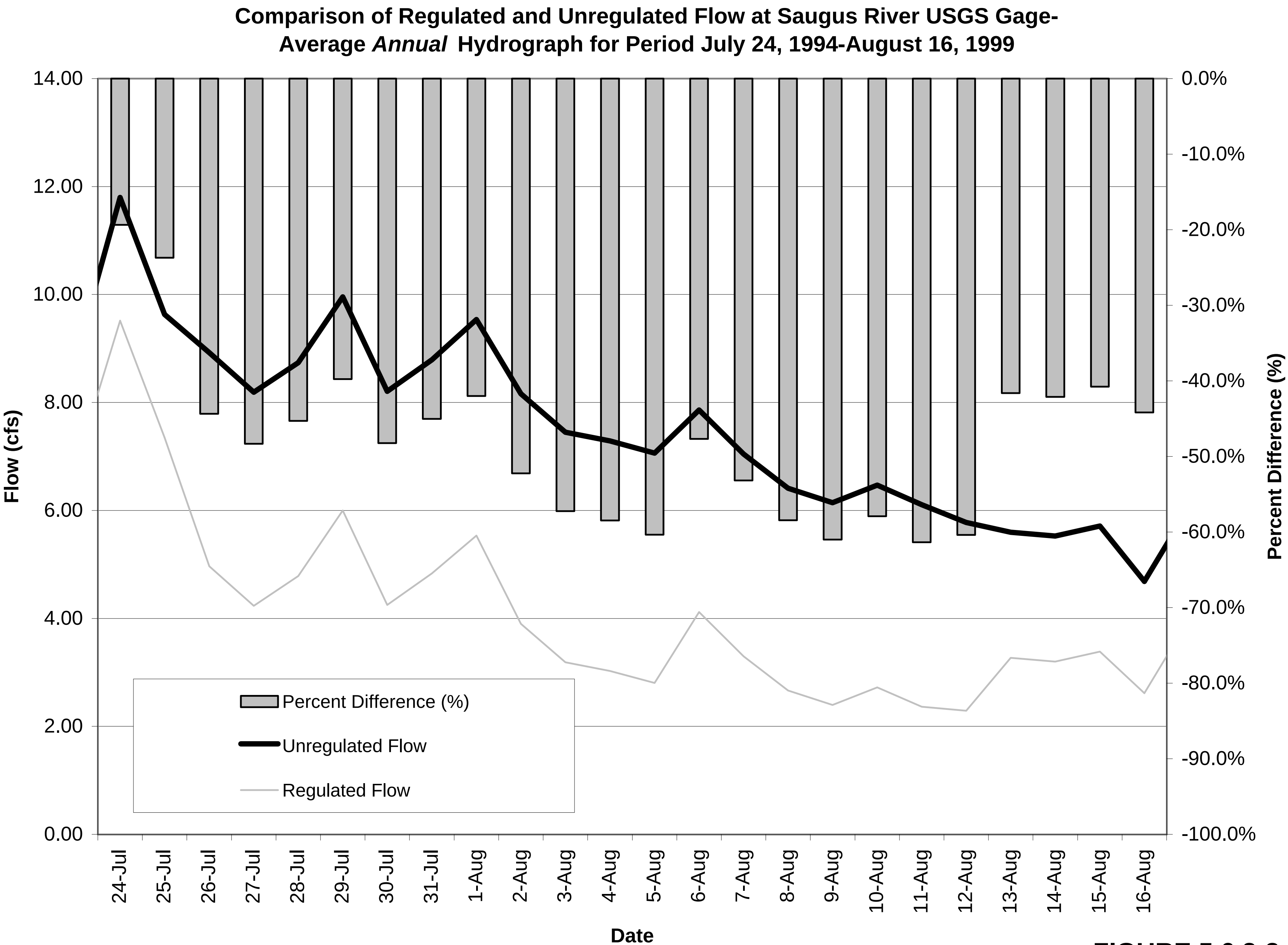
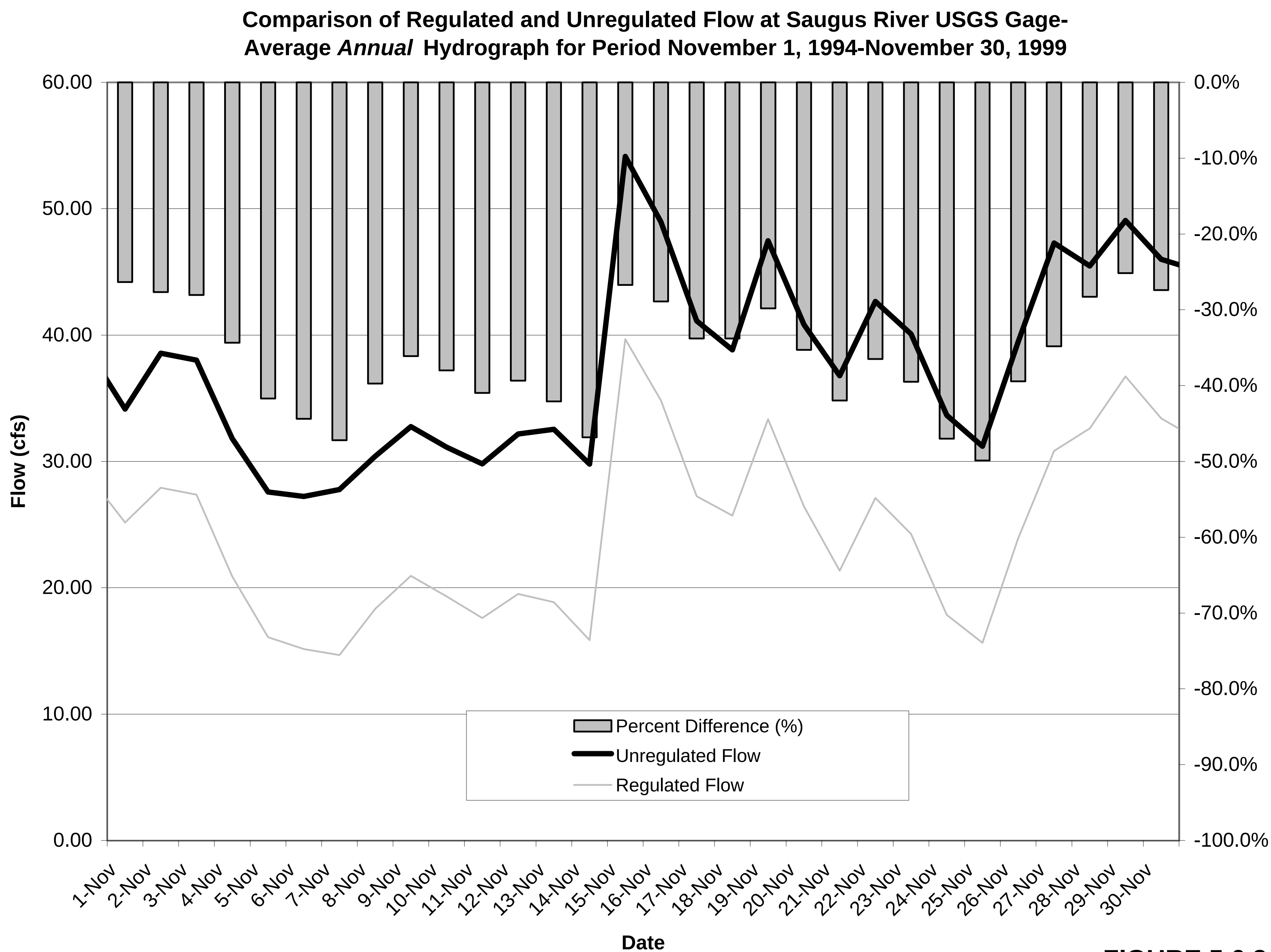

Comparison of Regulated and Unregulated Flow at Saugus River USGS Gage-
Average Annual Hydrograph for Period July 24, 1994-August 16, 1999
Flow (cfs)
Percent Difference (%)
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0.0%
-10.0%
-20.0%
-30.0%
-40.0%
-50.0%
-60.0%
-70.0%
-80.0%
-90.0%
-100.0%
Percent Difference (%)
Unregulated Flow
Regulated Flow
24-Jul
25-Jul
26-Jul
27-Jul
28-Jul
29-Jul
30-Jul
31-Jul
1-Aug
2-Aug
3-Aug
4-Aug
5-Aug
6-Aug
7-Aug
8-Aug
9-Aug
10-Aug
11-Aug
12-Aug
13-Aug
14-Aug
15-Aug
16-Aug
Date

FIGURE 5.6.2-3



Comparison of Regulated and Unregulated Flow at Saugus River USGS Gage-
Average *Annual* Hydrograph for Period November 1, 1994-November 30, 1999
Flow (cfs)
60.00
50.00
40.00
30.00
20.00
10.00
0.00
Percent Difference (%)
0.0%
-10.0%
-20.0%
-30.0%
-40.0%
-50.0%
-60.0%
-70.0%
-80.0%
-90.0%
-100.0%
Percent Difference (%)
Unregulated Flow
Regulated Flow
1-Nov
2-Nov
3-Nov
4-Nov
5-Nov
6-Nov
7-Nov
8-Nov
9-Nov
10-Nov
11-Nov
12-Nov
13-Nov
14-Nov
15-Nov
16-Nov
17-Nov
18-Nov
19-Nov
20-Nov
21-Nov
22-Nov
23-Nov
24-Nov
25-Nov
26-Nov
27-Nov
28-Nov
29-Nov
30-Nov
Date

FIGURE 5.6.2-4

Comparison of Regulated and Unregulated Flow at Saugus River USGS Gage-
Hydrograph for Period October 17-November 11, 1996

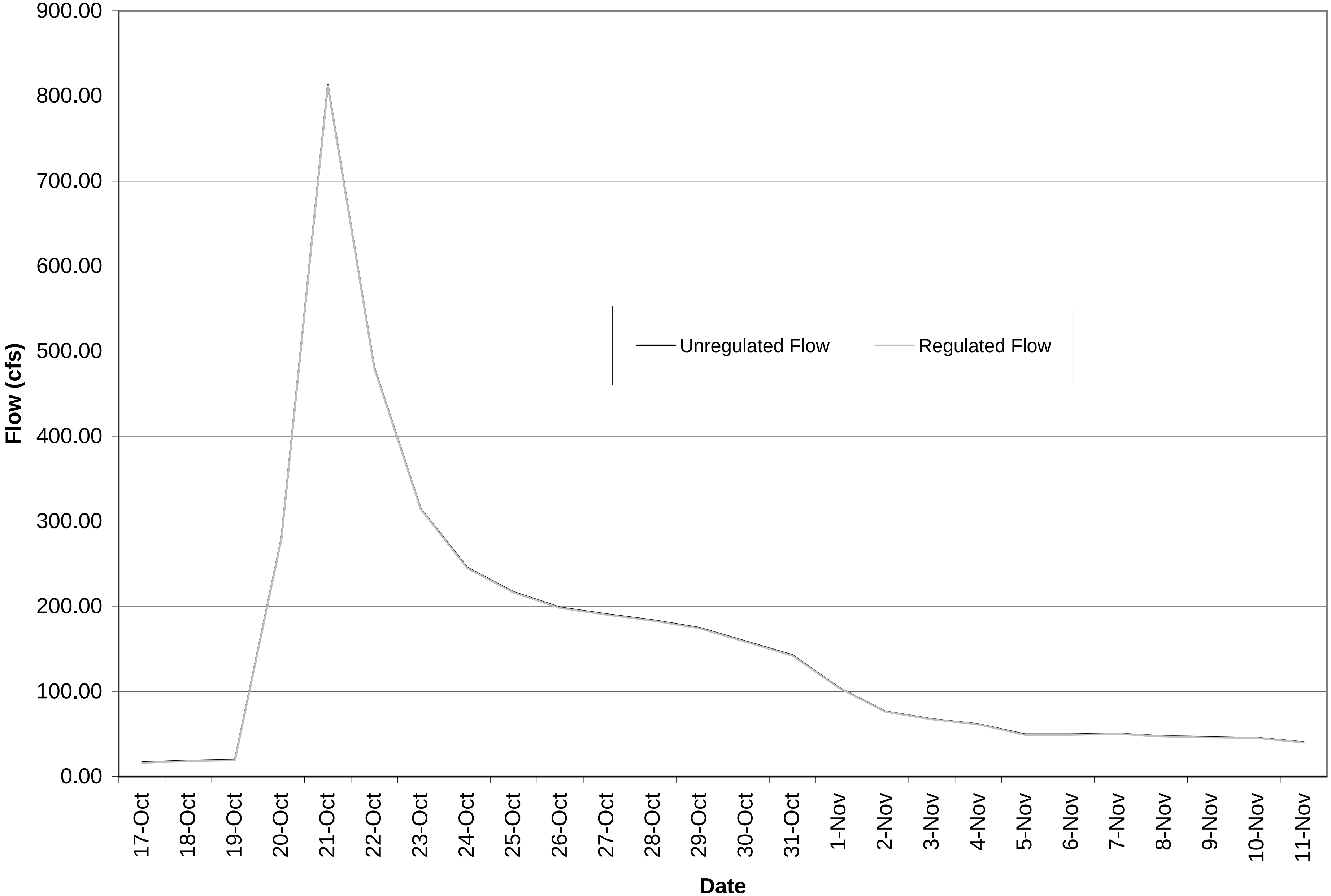
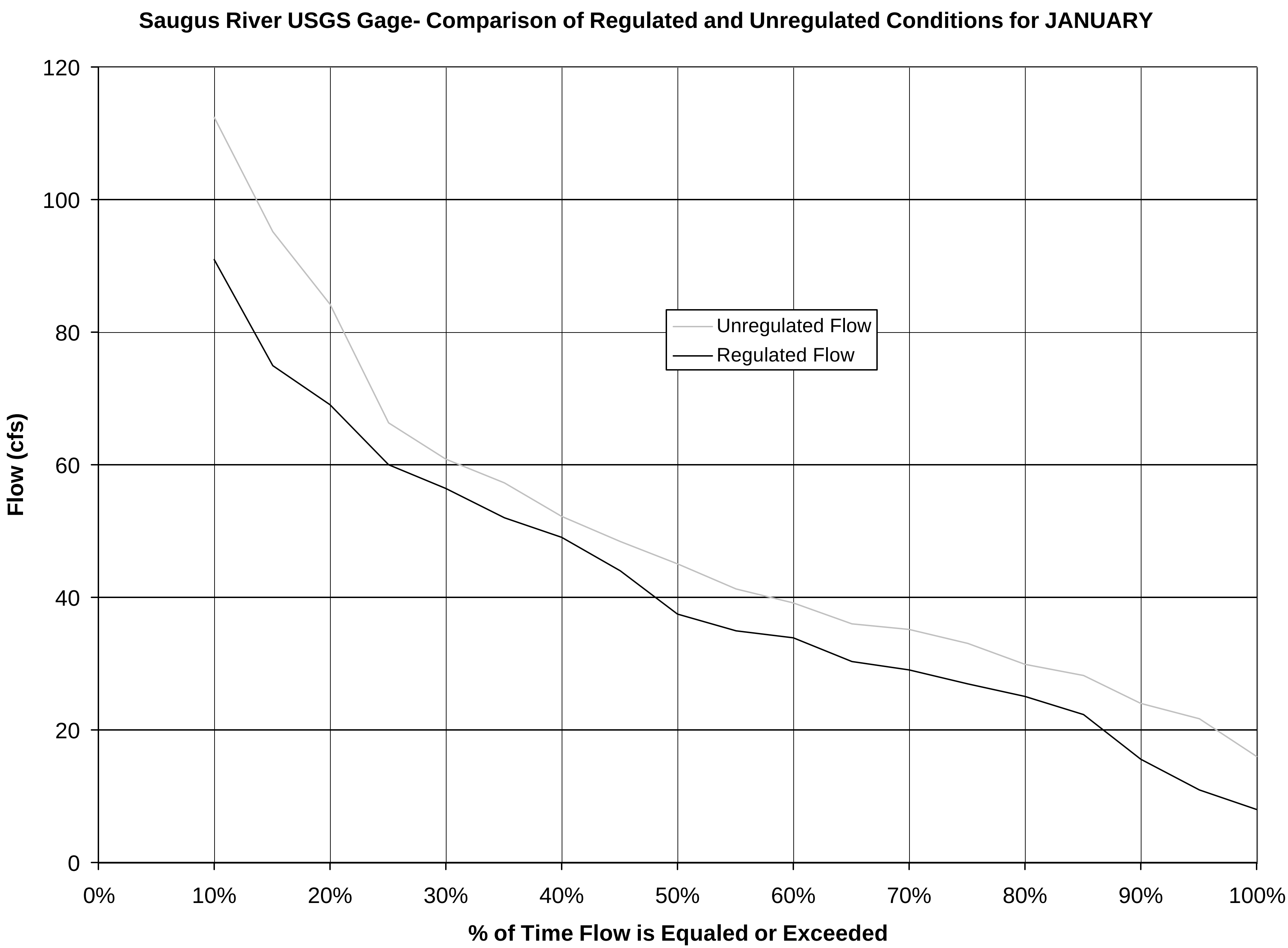


FIGURE 5.6.2-5



Saugus River USGS Gage- Comparison of Regulated and Unregulated Conditions for JANUARY
120
100
80
60
40
20
0
Flow (cfs)
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
% of Time Flow is Equaled or Exceeded
Unregulated Flow
Regulated Flow

FIGURE 5.6.3-1

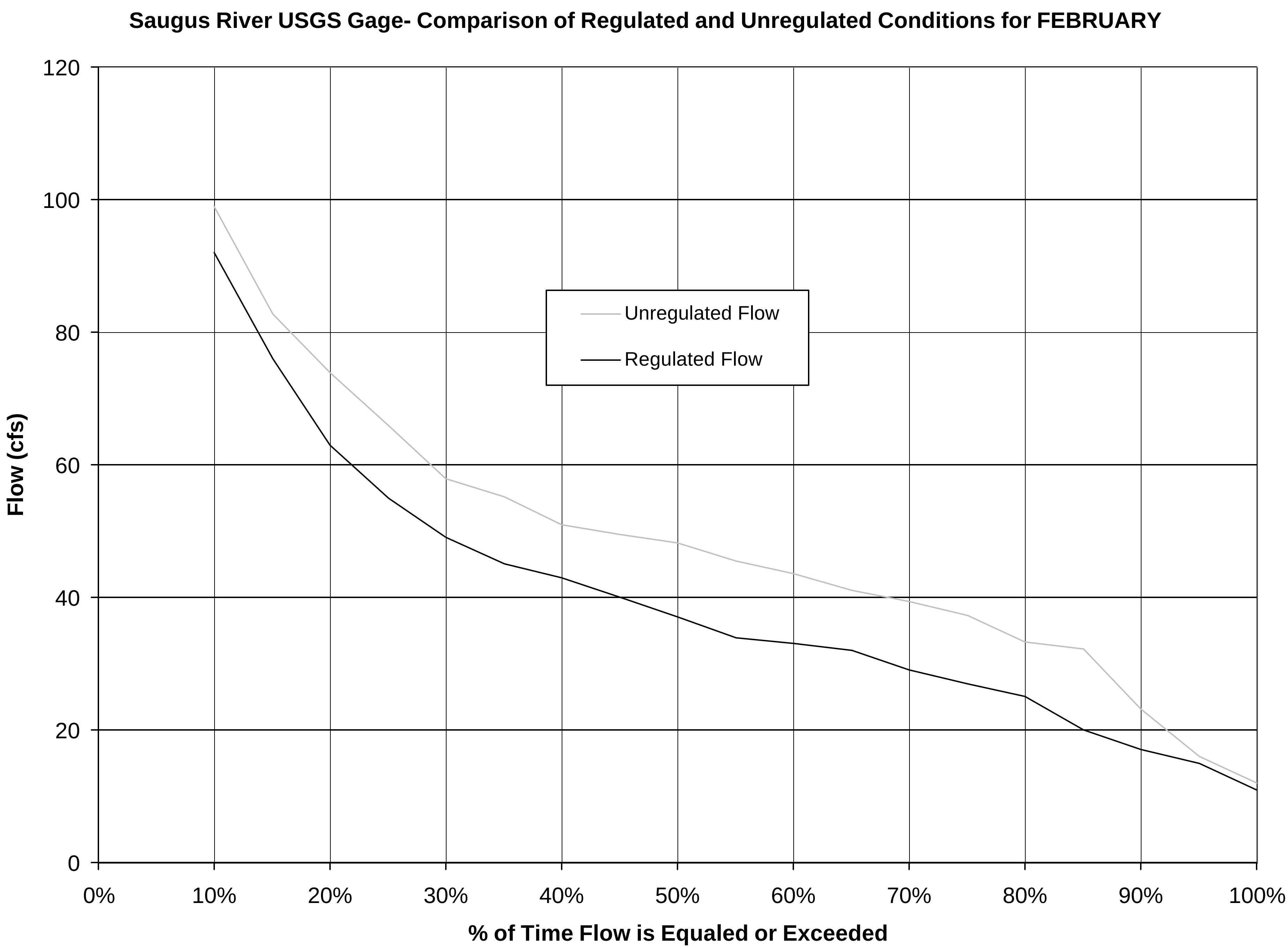

Saugus River USGS Gage- Comparison of Regulated and Unregulated Conditions for FEBRUARY
120
100
80
60
40
20
0
Flow (cfs)
Unregulated Flow
Regulated Flow
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
% of Time Flow is Equaled or Exceeded

FIGURE 5.6.3-2

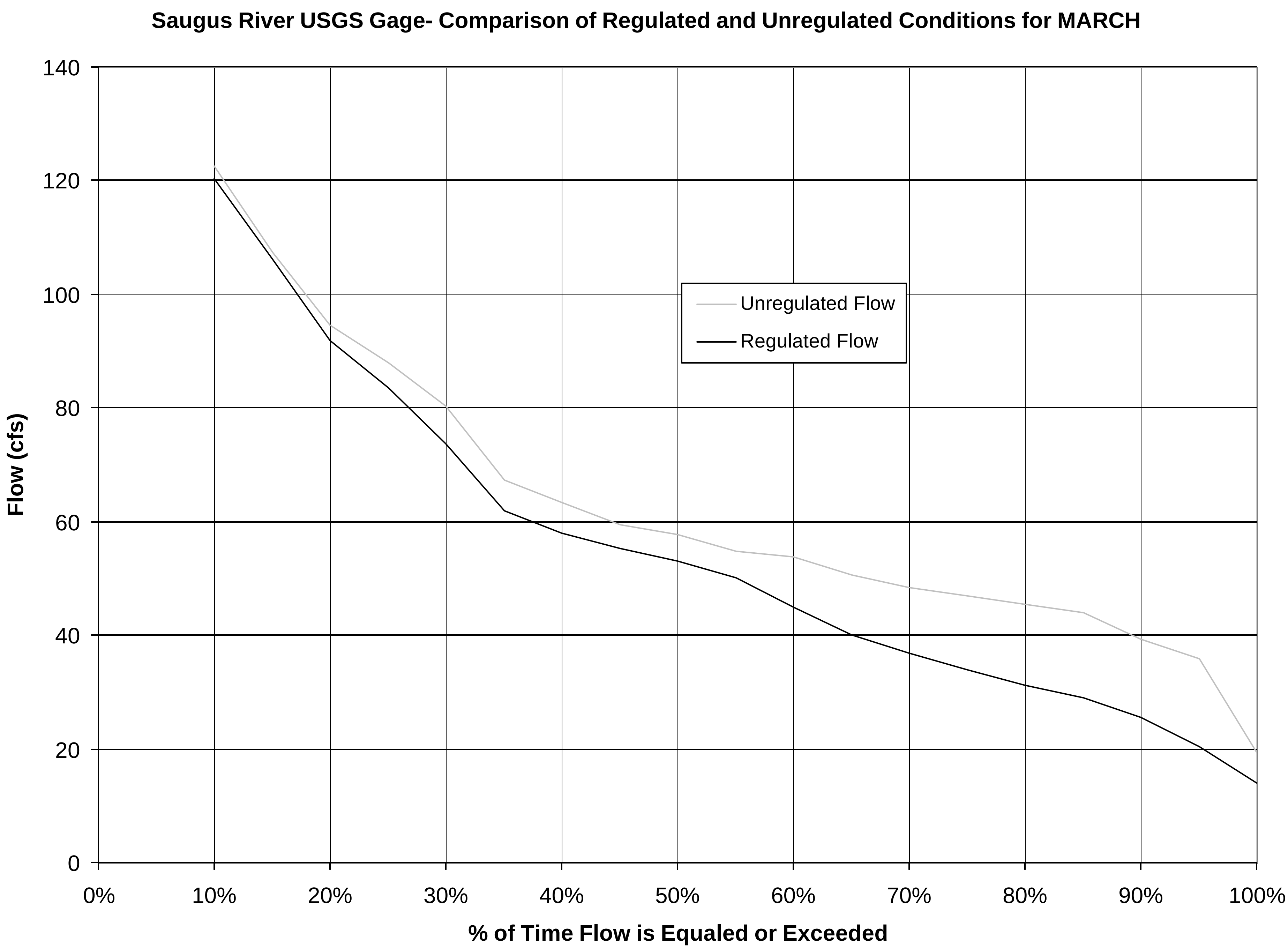

Saugus River USGS Gage- Comparison of Regulated and Unregulated Conditions for MARCH
Flow (cfs)
0
20
40
60
80
100
120
140
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
% of Time Flow is Equaled or Exceeded
Unregulated Flow
Regulated Flow

FIGURE 5.6.3-3

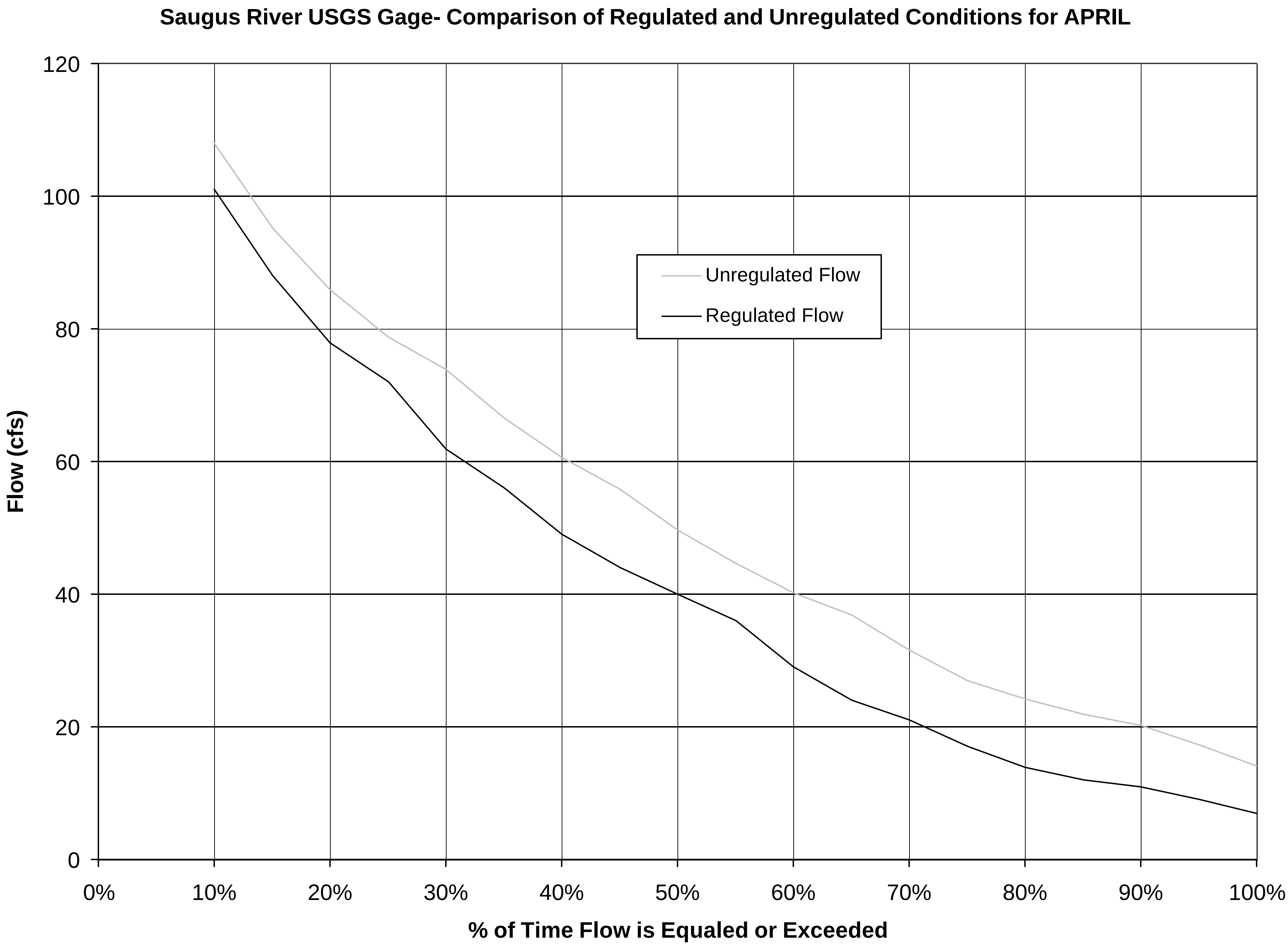

Saugus River USGS Gage- Comparison of Regulated and Unregulated Conditions for APRIL
Flow (cfs)
120
100
80
60
40
20
0
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
% of Time Flow is Equaled or Exceeded
Unregulated Flow
Regulated Flow

FIGURE 5.6.3-4

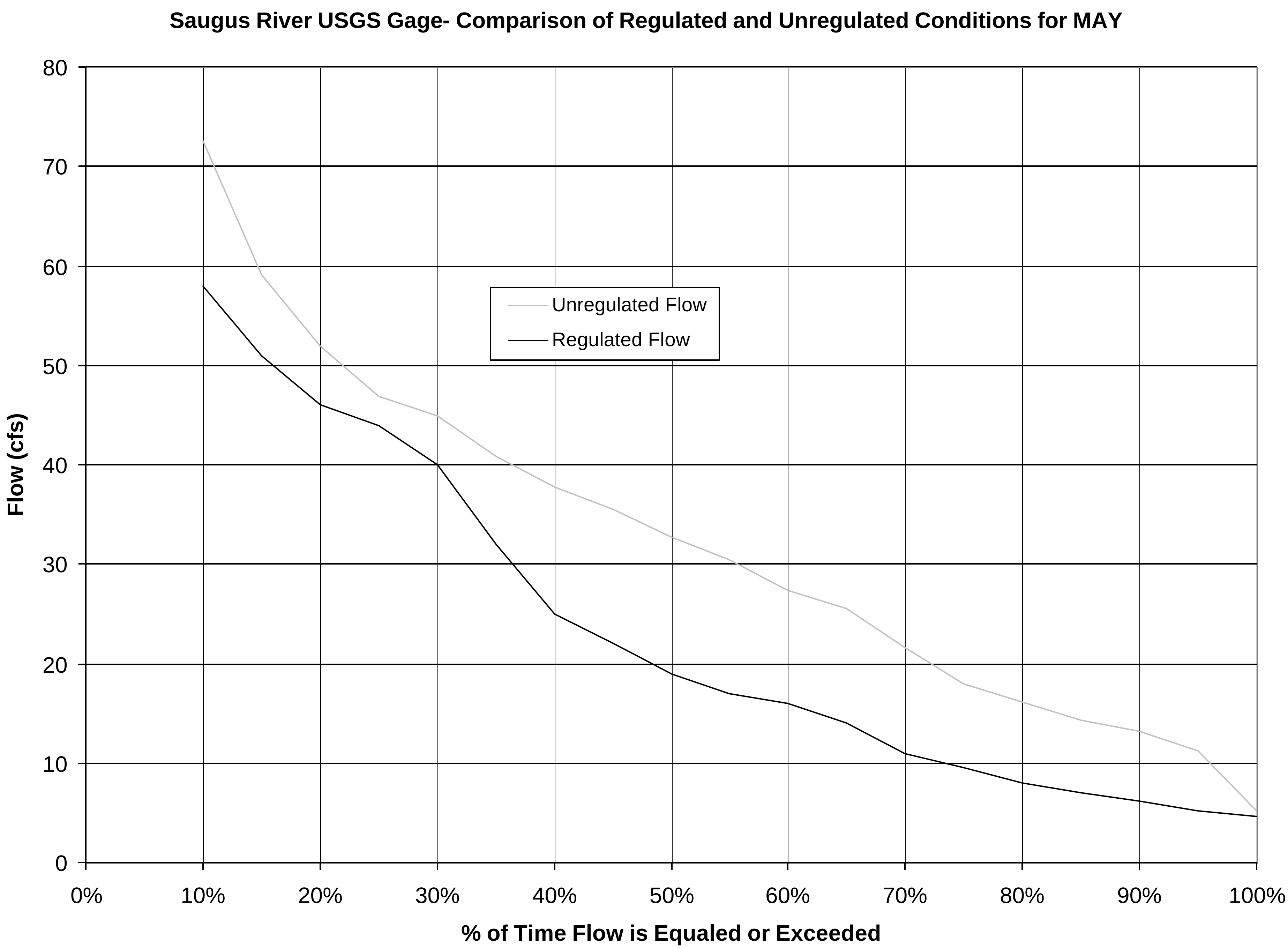

Saugus River USGS Gage- Comparison of Regulated and Unregulated Conditions for MAY
Unregulated Flow
Regulated Flow
Flow (cfs)
0
10
20
30
40
50
60
70
80
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
% of Time Flow is Equaled or Exceeded

FIGURE 5.6.3-5

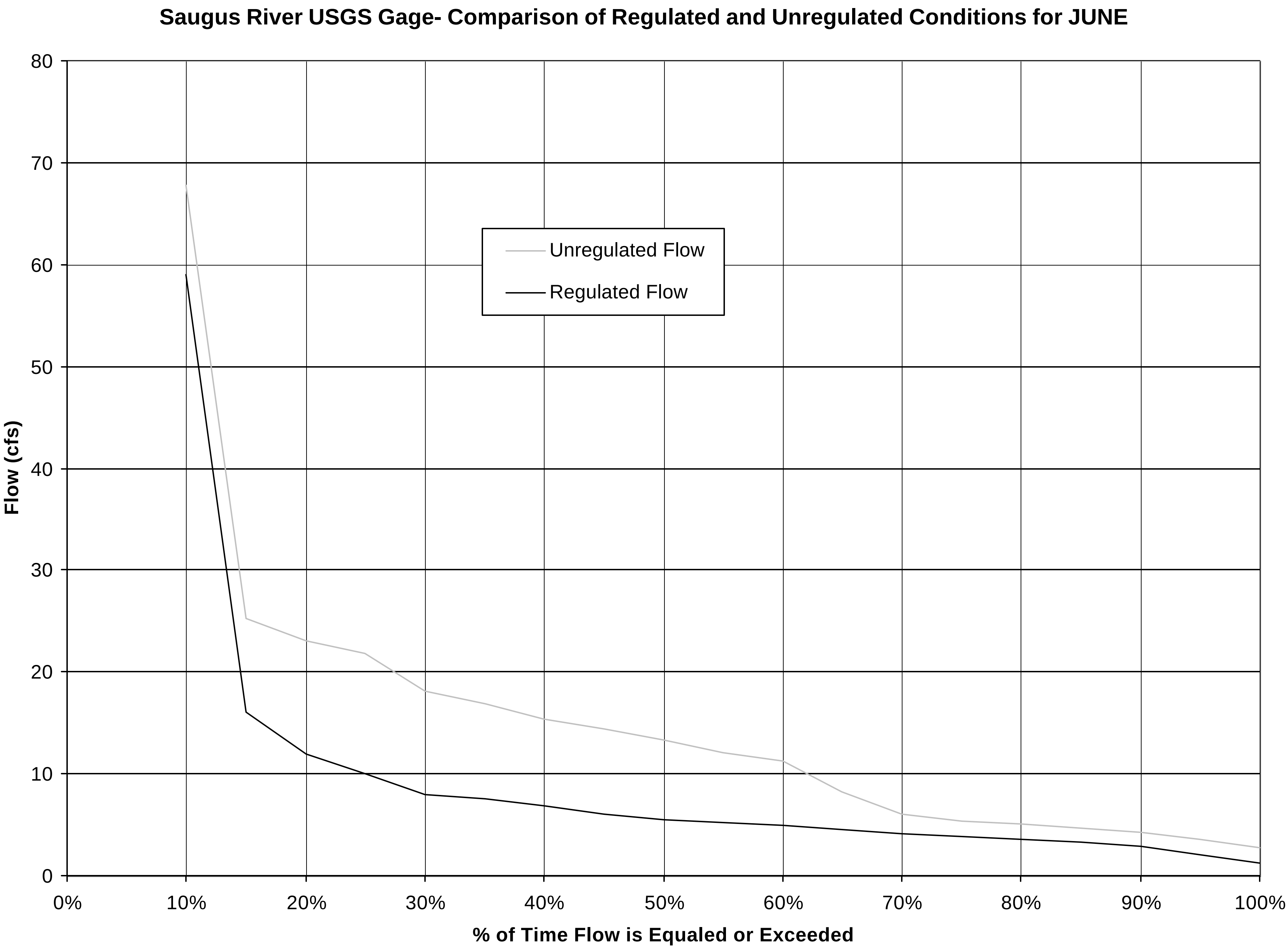

Saugus River USGS Gage- Comparison of Regulated and Unregulated Conditions for JUNE
Unregulated Flow
Regulated Flow
Flow (cfs)
80
70
60
50
40
30
20
10
0
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
% of Time Flow is Equaled or Exceeded

FIGURE 5.6.3-6

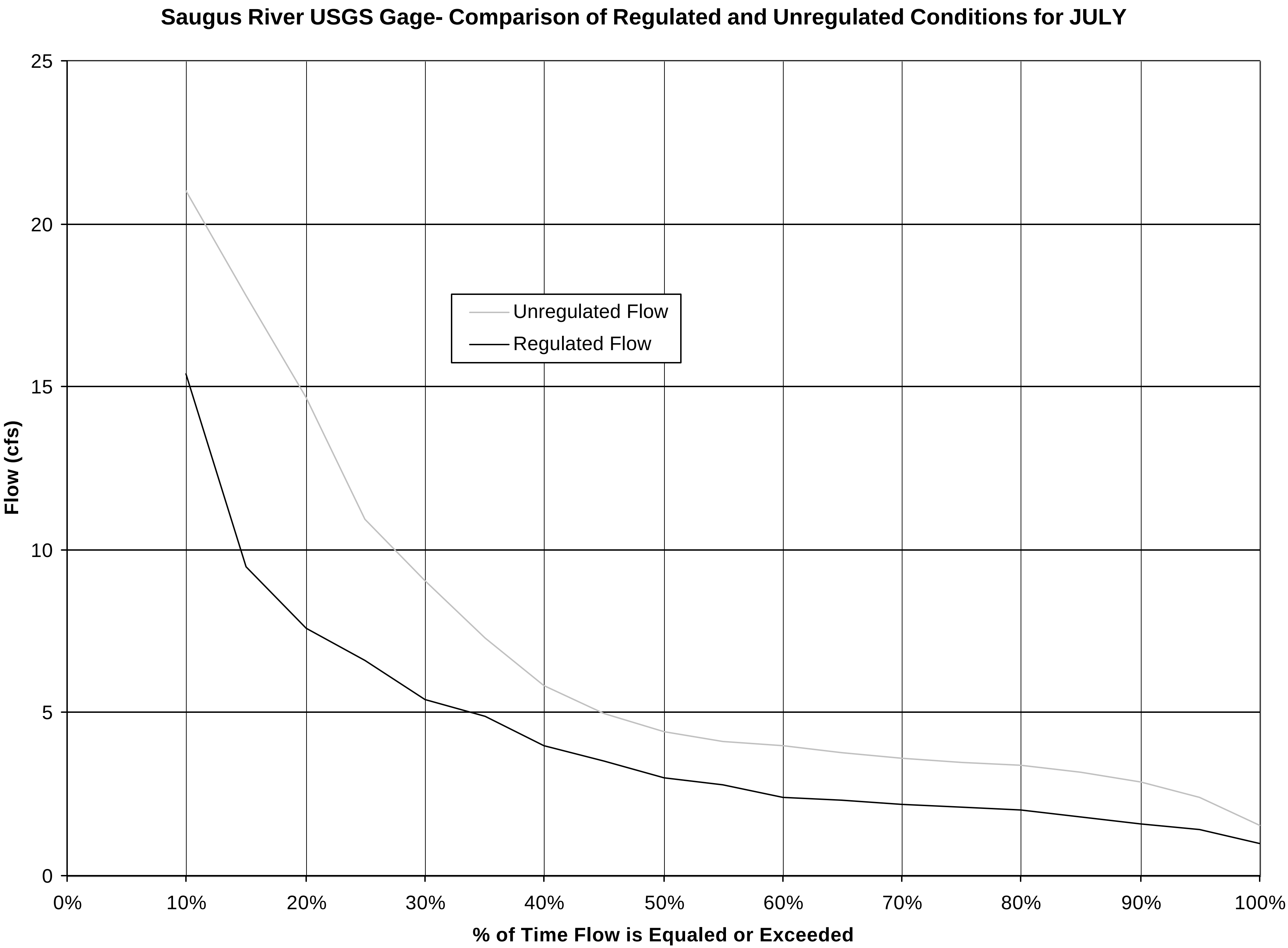
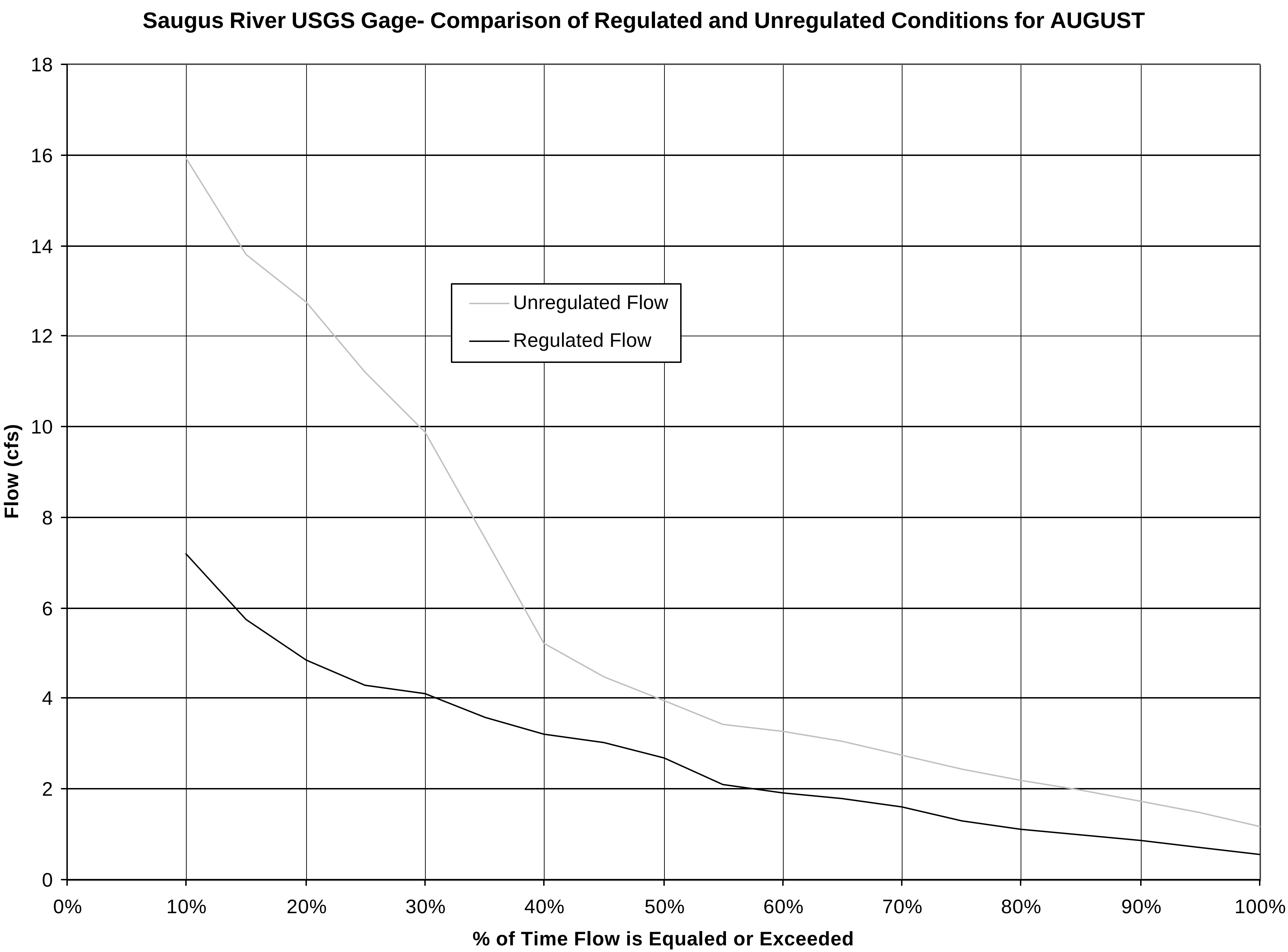

Saugus River USGS Gage- Comparison of Regulated and Unregulated Conditions for JULY
Flow (cfs)
25
20
15
10
5
0
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
% of Time Flow is Equaled or Exceeded
Unregulated Flow
Regulated Flow

FIGURE 5.6.3-7



Saugus River USGS Gage- Comparison of Regulated and Unregulated Conditions for AUGUST
Flow (cfs)
0
2
4
6
8
10
12
14
16
18
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
% of Time Flow is Equaled or Exceeded
Unregulated Flow
Regulated Flow

FIGURE 5.6.3-8

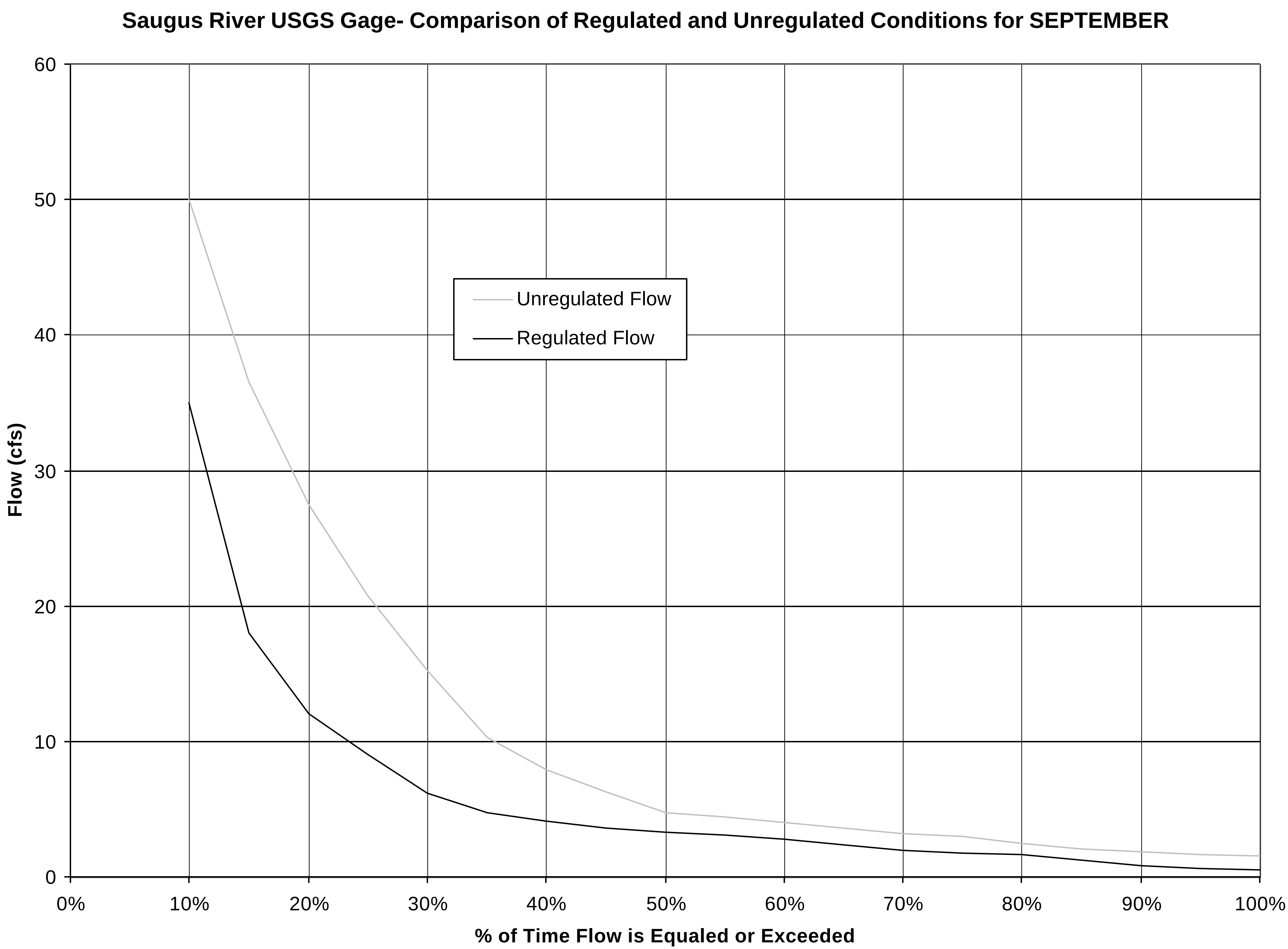

Saugus River USGS Gage- Comparison of Regulated and Unregulated Conditions for SEPTEMBER
Unregulated Flow
Regulated Flow
Flow (cfs)
0
10
20
30
40
50
60
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
% of Time Flow is Equaled or Exceeded

FIGURE 5.6.3-9

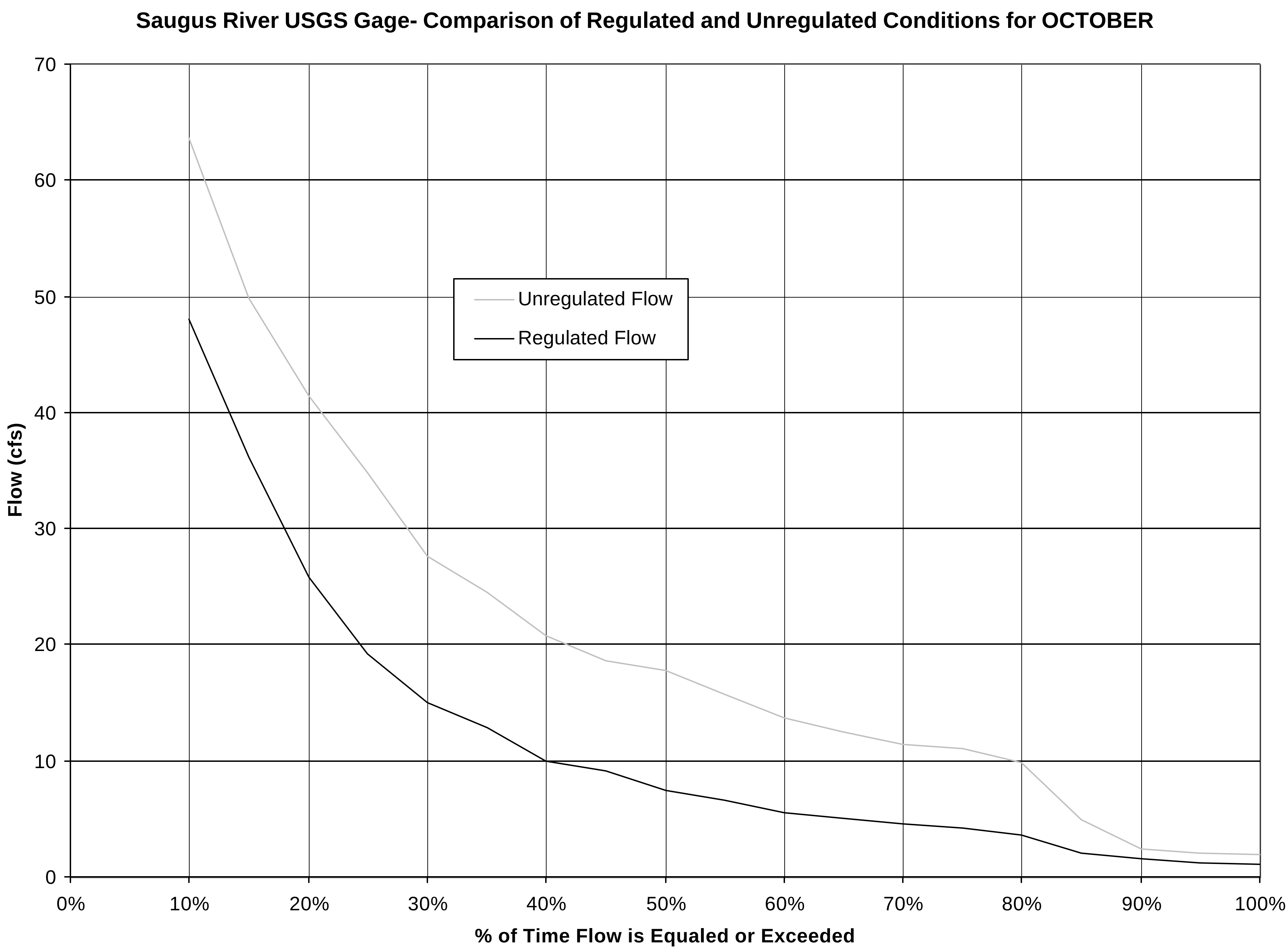


FIGURE 5.6.3-10

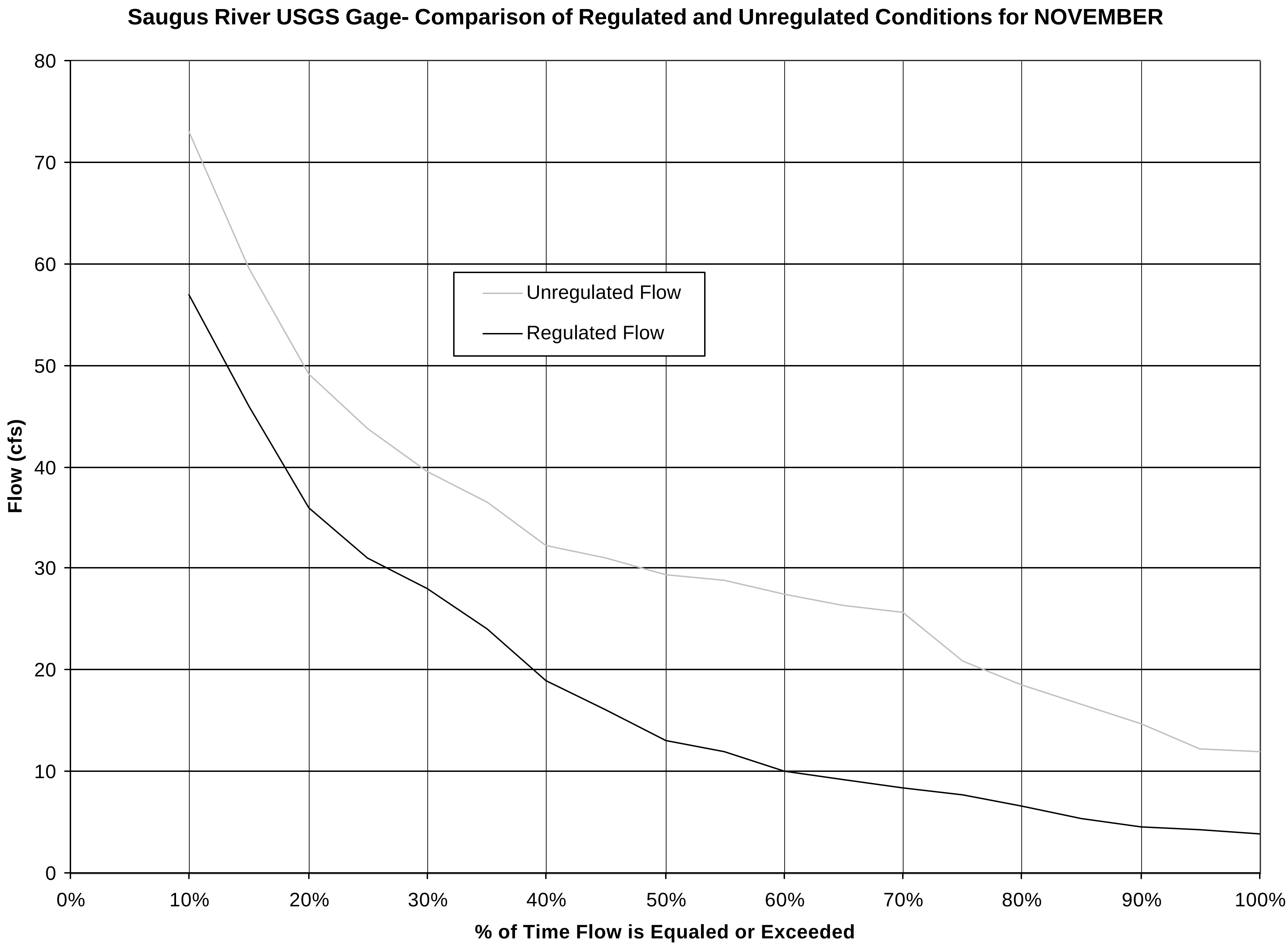


FIGURE 5.6.3-11

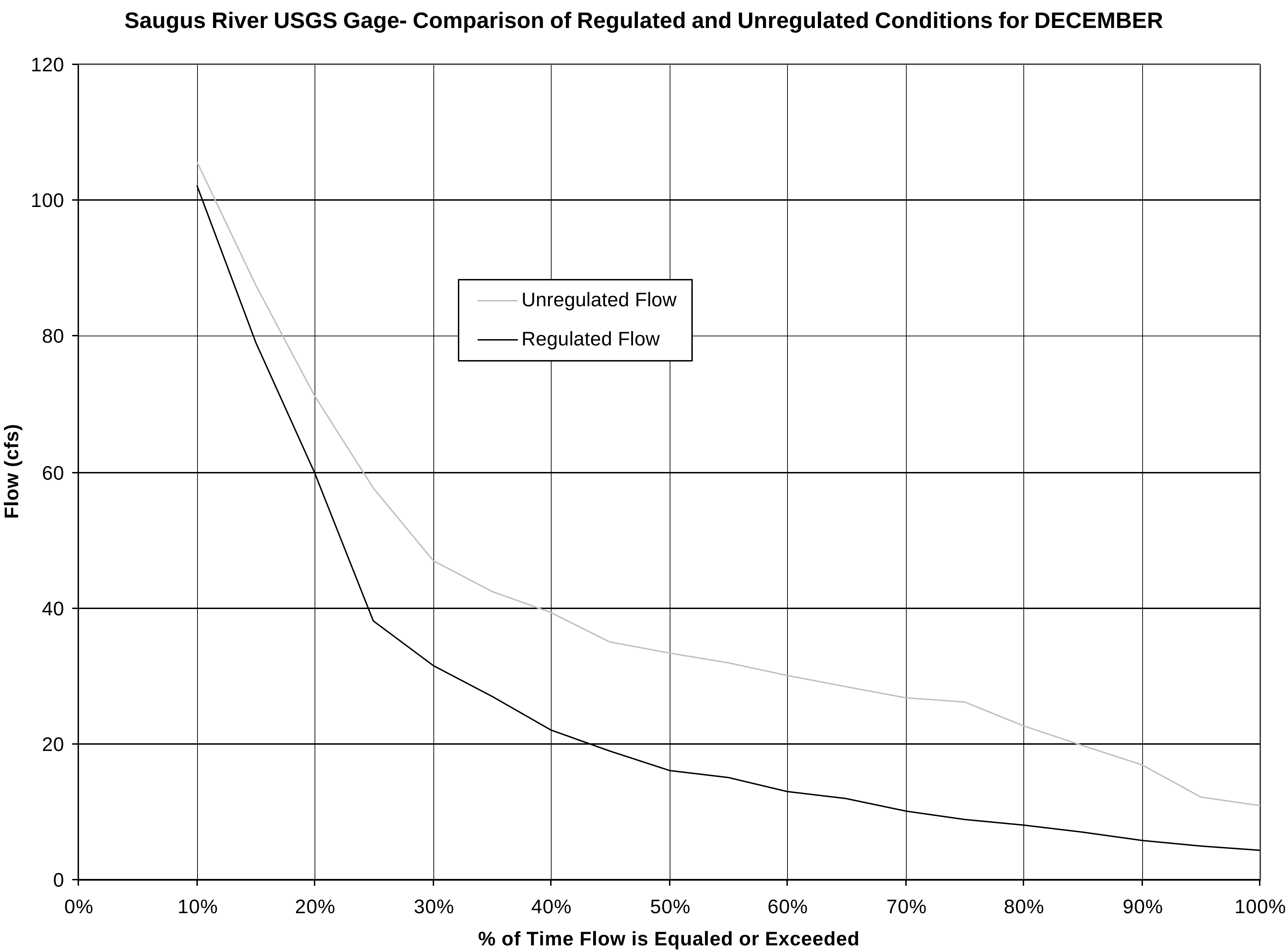


FIGURE 5.6.3-12

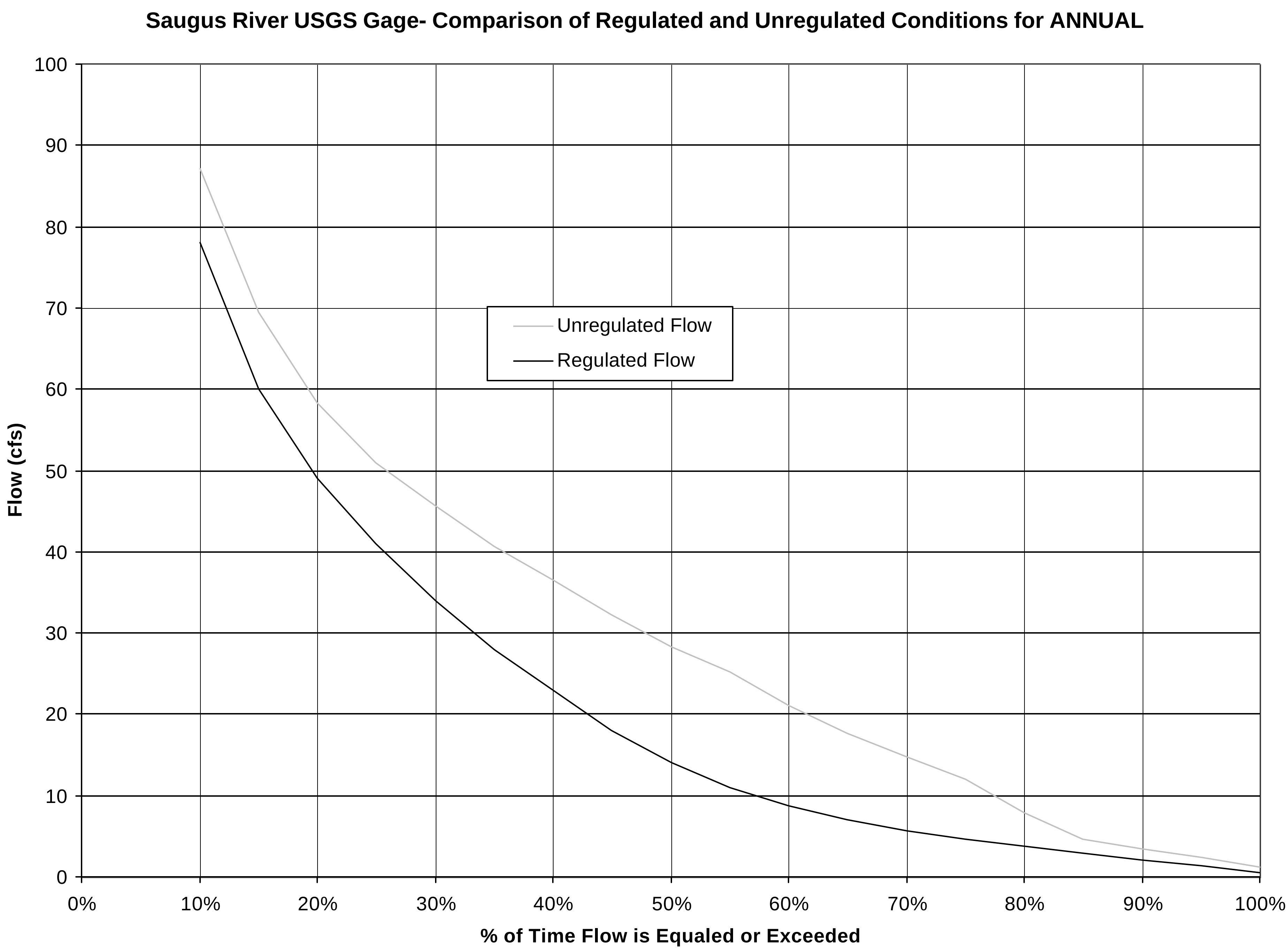


FIGURE 5.6.3-13

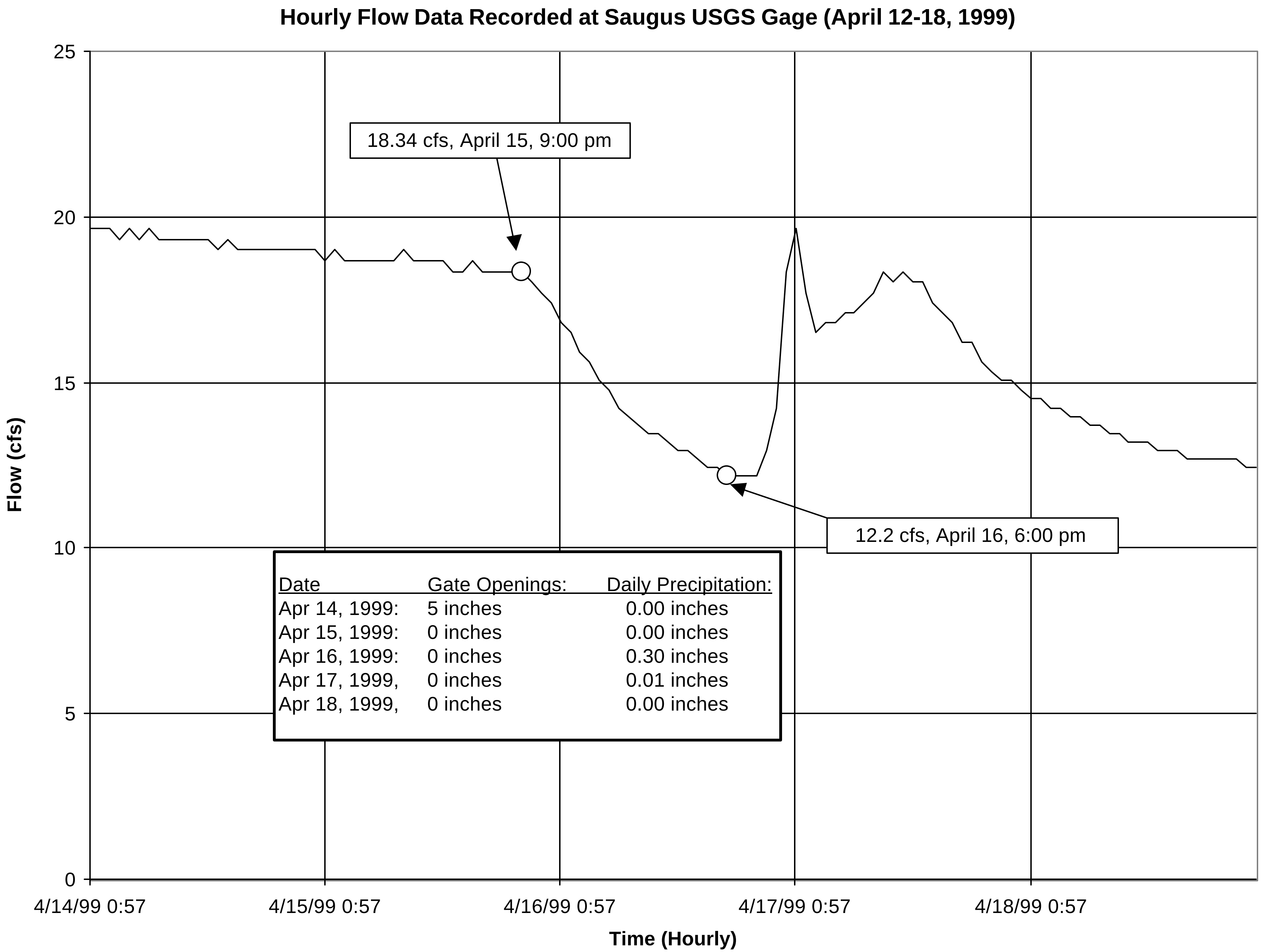

Hourly Flow Data Recorded at Saugus USGS Gage (April 12-18, 1999)
Flow (cfs)
25
20
15
10
5
0
18.34 cfs, April 15, 9:00 pm
12.2 cfs, April 16, 6:00 pm
Date Gate Openings: Daily Precipitation:
Apr 14, 1999: 5 inches 0.00 inches
Apr 15, 1999: 0 inches 0.00 inches
Apr 16, 1999: 0 inches 0.30 inches
Apr 17, 1999, 0 inches 0.01 inches
Apr 18, 1999, 0 inches 0.00 inches
4/14/99 0:57
4/15/99 0:57
4/16/99 0:57
4/17/99 0:57
4/18/99 0:57
Time (Hourly)

FIGURE 5.6.4-1

6.0 Flood Control

6.1 Previous Reports

The following reports were reviewed, which pertain to flooding issues along the Saugus River (some tributaries) and the coast.

- Saugus River Flood Control Improvements, Report to the Saugus River Watershed Committee, Camp, Dresser and McKee, Inc, March 1992.
- Federal Emergency Management Agency, Flood Insurance Studies and Flood Boundary and Floodway Map in the Saugus and Lynnfield.
- Survey Report on Saugus and Pines Rivers and Adjacent Coastal Areas of Massachusetts for Flood Control and Navigation

The most current document is the report prepared by CDM. It is noted in CDM's report that the Saugus River and associated tributaries, Beaverdam Brook and Mill River, have experienced chronic flooding problems in the bordering neighborhoods since the 1950's. In 1992, CDM conducted a flood study of the Saugus River Basin from the Lake Quannapowitt outlet to Center Street in Saugus. The purpose of the study was to provide a comprehensive description of current drainage and flooding problems, the alternatives for alleviating these problems and a recommended program of flood control improvements.

A summary of CDM findings are shown below:

- Most of the Saugus River is characterized as being very flat and sluggish flowing with several large marshy areas that have the ability to store large volumes of floodwaters. These areas include the area above the Reading drainage canal, Reedy Meadows, areas along the Mill River, and areas both upstream and downstream of Route 1. This storage capacity is a critical element of the watershed hydrology that helps maintain flows throughout the system at relatively low rates.

- The area surrounding the majority of the Saugus River waterway is heavily developed. In many areas the development has encroached into land that was originally floodplains- the low-lying land adjacent to the waterways or marshes are periodically subject to flooding. Development in areas such as Perry Avenue in Lynnfield, Paon Boulevard in Wakefield and Route 1 in Saugus is often most subject to flooding, drainage problems, or high groundwater levels due to the fundamental nature of the land it is built on.

- The LWSC diversion at the Diversion Dam to Hawkes Pond travels along a canal. The diversion capacity is currently limited by the flat grade of the diversion canal, and the inability to regulate Hawkes Pond water levels for flood control purposes.

- The Reedy Meadow area in Wakefield and Lynnfield is exhibiting a natural eutrophication process that causes the marsh to fill in over time and become overgrown as a swamp or meadow. This process has been accelerated by development activities in the surrounding area that produces heavy nutrient and sediment loadings. This is a slow process that will continue over time to reduce the flow carrying capacity of the stream channels passing through the marsh.

- The channel system through Reedy Meadows has become restrictive to flows due to clogging of the culverts through the B&M Railroad embankment, which bisects the meadow, and through clogging of the stream channels with sediments and vegetation. These factors greatly contribute to the normally high water levels in the upper reaches of the meadow.

- The lack of consistent channel maintenance to keep the channels at an appropriate flow section is a problem throughout much of the Saugus River system. This appears to be due, in part, to the multi-jurisdictional nature of the watershed.

- The flooding problem in the upper Mill River area beginning near Fosters Lane is due to overflows coming in from interconnections with the Reedy Meadow in the area of the Route 128-Railroad underpass. While these inflows also contribute to flooding downstream on the Mill River, the flooding downstream of New Salem Street is primarily due to a backwater effect extending back along the virtually flat slope of the river from its confluence with the Saugus River.

- A reported flooding problem occurs along the Saugus River just upstream of its crossing of Route 1, affecting the MDC's Camp Nihan, the Saugus Plaza shopping center, and several commercial establishments along Route 1. This appears to be shallow parking lot flooding that occurs as a part of the flood storage and ponding that occurs behind the culvert at Route 1.

6.2 Evaluation of Existing Peak Flow Conditions

A review of past instantaneous peak flows on the Saugus, Ipswich and Aberjona Rivers was conducted from USGS gage records to identify the seasonal timing of high flows. Information on these gages is listed in Table 6.2-1.

Table 6.2-1: USGS Gages Located on or near the Saugus River

Gage No.	Gage Name	Drainage Area (sq mi)	Period of Record	Regulated
01102345	Saugus River at the Saugus Ironworks, MA	23.3 sq mi	1994-2000	Yes
01102500	Aberjona River at Winchester, MA	24.7 sq mi	1940-2000	Yes
01101500	Ipswich River at South Middleton, MA	44.5 sq mi	1938-2000	Yes

The annual instantaneous peak flow was obtained from USGS records along with the date (month) of occurrences. This analysis was conducted to determine when (month) the annual peak flow is likely to occur relative to the overall storage capacity of reservoirs within the Saugus River Basin. Figure 6.2-1 shows the percentage break down of annual peak flows on a monthly basis for the gages listed in Table 6.2-1. As expected, the majority of annual peak flows occur during the typical high runoff period of March and April. However, the Saugus River peak flow events were distributed among the months as shown later.

Within the LWSC reservoir system there are four storage facilities, which drain a total watershed area of approximately 5.36 mi^2. During the months when high flows are most likely to occur (March and April), the reservoirs are close to being full (see Figure 6.2-2), and provide only limited buffering capacity. The majority of reservoir refill occurs during the months of December-February. During this refill period, diversions from the Ipswich River are the highest (see Figure 6.2-2). One alternative to consider, which may warrant further evaluation, is to limit the Ipswich River withdrawals in the winter, leaving more storage capacity in the LWSC reservoirs. In doing so, additional storage capacity could be available to store the high spring runoff events around each of the LWSC storage reservoirs.

Besides direct runoff around the four LWSC storage reservoirs, LWSC may also divert flow from the Saugus River at the Diversion Dam during flood events. However, the ability to move large quantities of water via the canal is limited by its mild slope, and the inability to regulate Hawkes Pond water levels for flood control purposes. The canal flow capacity is approximately 17 MGD (26 cfs). To put this flow capacity into perspective, the drainage area at the Diversion Dam is approximately 10.5 mi^2. The flow per square mile that can be diverted is equivalent to 2.5 cfsm (26 cfs/10.5 mi^2). Since the Saugus River gage was placed into operation in 1994, the instantaneous peak flows are as follows: (measured at Ironworks)

Date	3/22/94	12/24/94	1/28/96	10/21/96	6/14/98	9/16/99	4/22/00
Peak Q (cfs)	251	166	262	942	577	211	298
Flow/mi^2	10.8	7.1	11.2	40.4	24.8	9.1	12.8
Flow at Diversion (cfs)	113.4	74.6	117.2	424.2	260.4	95.6	134.4

Since the flow capacity of the canal is 26 cfs, it effectively does not significantly help flood conditions below the Diversion Dam. For some flood peaks, the 26 cfs diversion could alleviate some flooding, but under large flood events, there is little reduction in downstream peak flows. In addition, when Hawkes Pond is at full capacity flow can actually move backwards from Hawkes Pond to the Diversion Dam due to the head differential. In summary, the existing LWSC storage system provides little flood capacity during the typical high runoff months.

Besides the LWSC reservoirs, Lake Quannapowitt is also drawn down during the winter period (1-1.5 feet) and refills during the high spring runoff period. It is unknown what level of flood control the lake provides. Other reservoirs/lakes in the watershed that could reduce/attenuate peak flows include Pillings Pond, Upper and Lower Pond (located in the Breakheart Reservation) and Crystal Lake. Joe Maney (Town Manager for the Town of Lynnfield) was contacted to provide information regarding the operation of 99-acre Pillings Pond. Consideration was given to drawing the pond down approximately one foot by November 1, however, for various reasons this procedure will not be followed in 2001. No formal drawdown policy is currently in-place and the storage capacity within the potential one-foot drawdown zone is unknown.

More recent data on flooding problems can be found in letters from Lynnfield and Wakefield residents, most of which were written in the fall of 1997. Many letters mentioned a specific flood event that occurred after a storm on October 18, 1996. However, most letters describe a situation that is more pervasive and chronic than previously reported. For example, several homeowners wrote that their need to use a sump pump in the basement has increased from 3 or 4 months out of the year to 12 months each year. Some people speculated that this trend was a result of new housing developments that had created more impervious surfaces and therefore more runoff.

6.3 Wetland

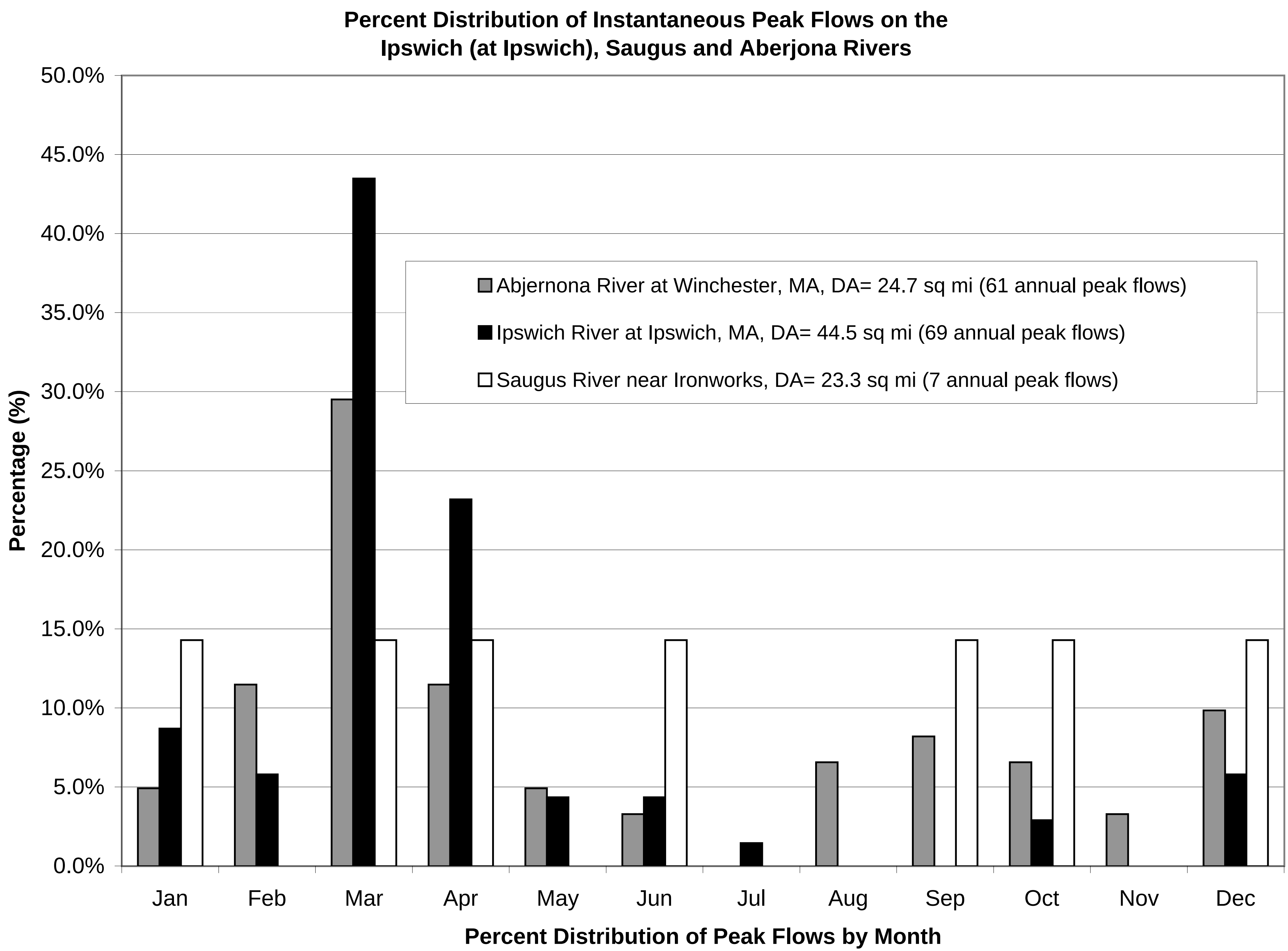
As noted in CDM's report, the wetland areas in the Saugus River waterway have become developed over time. In particular the Reedy Meadows wetland has become filled in over time, which has affected the flood storage capacity of the wetland. Wetlands serve a vital role during flood periods by storing large quantities of water and attenuating the flood hydrograph. A review of topographic maps of the Reedy Meadows wetland from 1944 and 1987 shows how the wetland has become filled in – see Figure 6.3-1 (1944 topographic map) and Figure 6.3-2 (1987 topographic map). Several wetland areas have been filled in including:

- several acres south of Pillings Pond
- the area west of the Colonial Country Club. The construction of Route 128 resulted in filling portions of Reedy Meadows

In addition to the loss of flood storage, the meadows have become overgrown due to the eutrophication process. The stream channel through the meadows and culverts has become clogged and thus flow movement is restricted, which has caused flooding concerns in the meadow area.

6.4 Summary

A complete examination of flood issues in the Saugus River Basin is beyond the scope of this report. We examined how existing sources of regulation could be modified to help alleviate flooding. Limited flood storage capacity is currently available within the LWSC system based on current operations. Further evaluation into reducing the Ipswich River water withdrawal in the winter, and allowing the storage reservoirs to refill during the high runoff period, may alleviate some flooding.



Percent Distribution of Instantaneous Peak Flows on the
Ipswich (at Ipswich), Saugus and Aberjona Rivers
50.0%
45.0%
40.0%
35.0%
30.0%
25.0%
20.0%
15.0%
10.0%
5.0%
0.0%
Percentage (%)
Abjernona River at Winchester, MA, DA= 24.7 sq mi (61 annual peak flows)
Ipswich River at Ipswich, MA, DA= 44.5 sq mi (69 annual peak flows)
Saugus River near Ironworks, DA= 23.3 sq mi (7 annual peak flows)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Percent Distribution of Peak Flows by Month

FIGURE 6.2-1

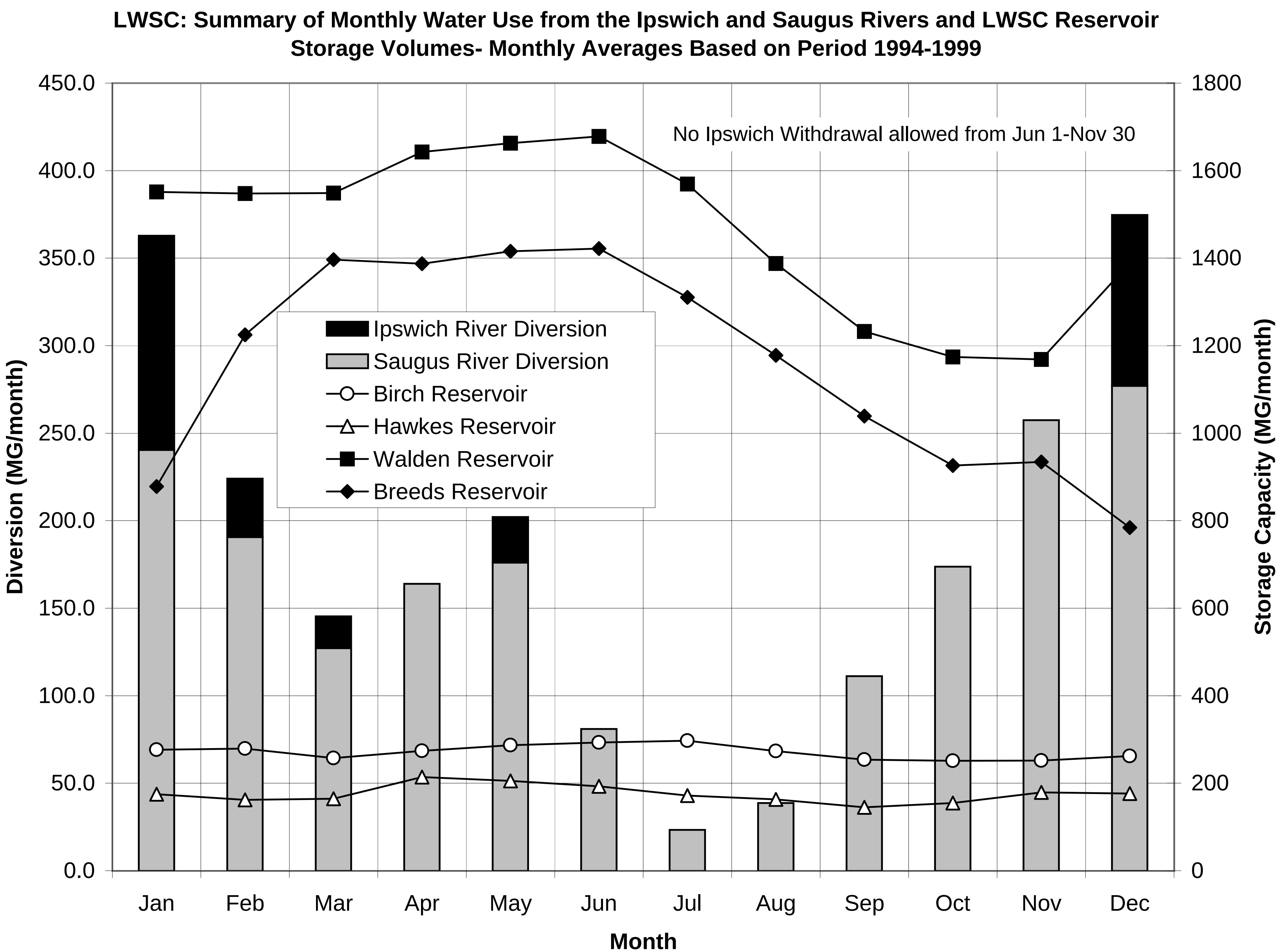

LWSC: Summary of Monthly Water Use from the Ipswich and Saugus Rivers and LWSC Reservoir Storage Volumes- Monthly Averages Based on Period 1994-1999
No Ipswich Withdrawal allowed from Jun 1-Nov 30
Ipswich River Diversion
Saugus River Diversion
Birch Reservoir
Hawkes Reservoir
Walden Reservoir
Breeds Reservoir
Diversion (MG/month)
Storage Capacity (MG/month)
Month
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
0.0
50.0
100.0
150.0
200.0
250.0
300.0
350.0
400.0
450.0
0
200
400
600
800
1000
1200
1400
1600
1800

FIGURE 6.2-2

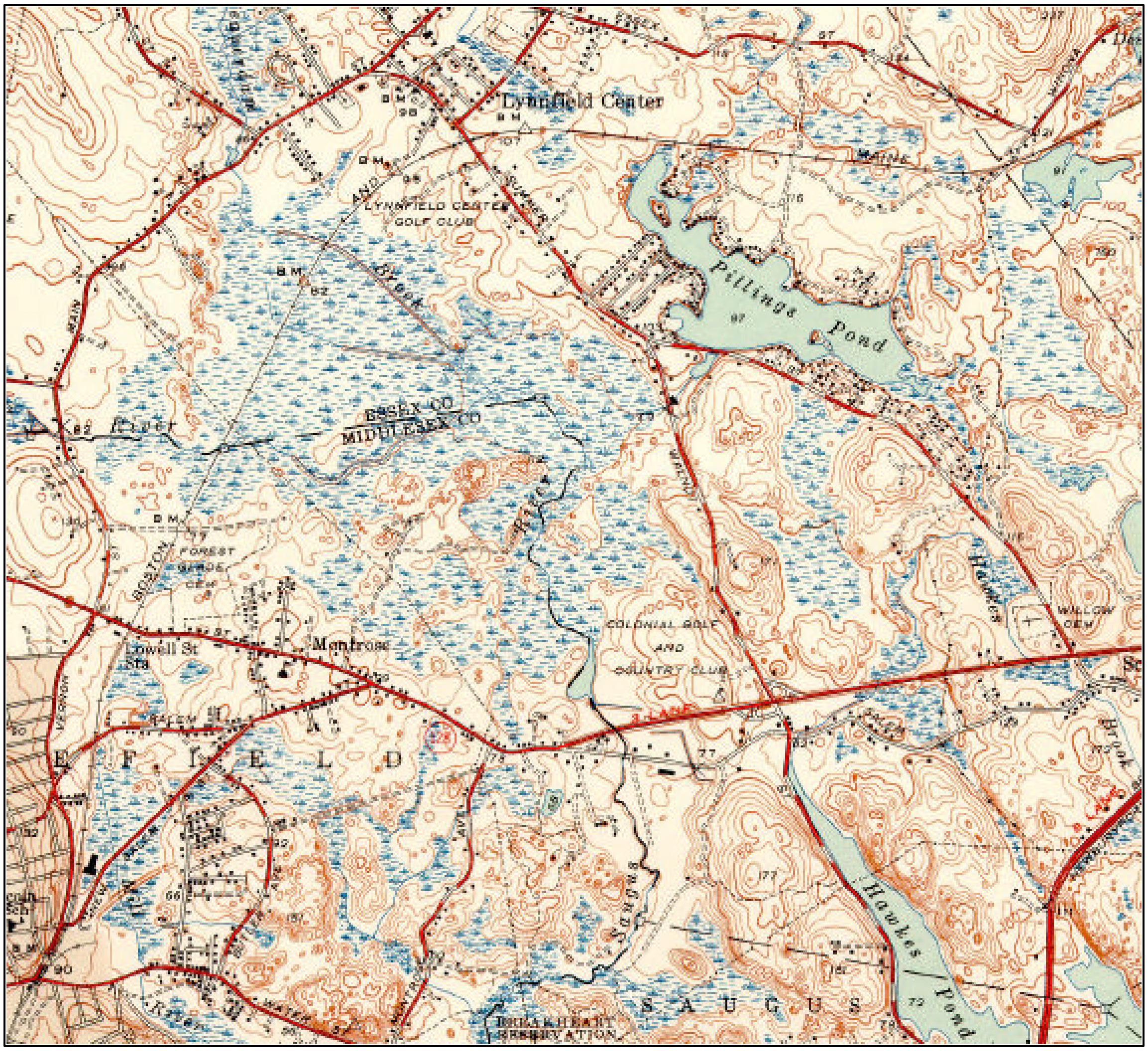


Figure 6.3-1: Topographic Map of the Reedy Meadows Wetland in 1944

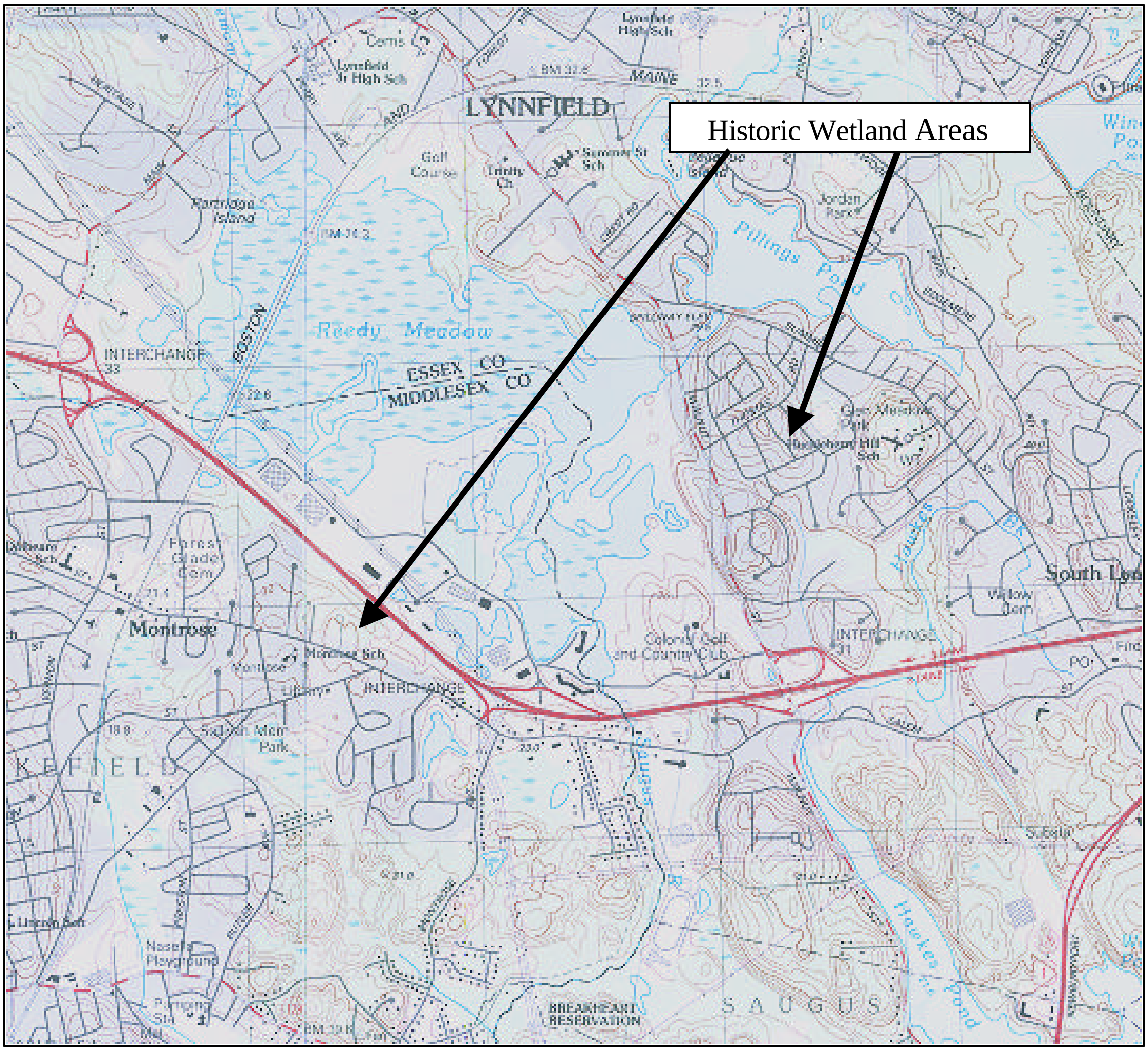


Figure 6.3-2: Topographic Map of the Reedy Meadows Wetland in 1987

7.0 Water Quality

7.1 Overview

Fish habitat in the Saugus River is controlled by microhabitat and macrohabitat variables. Microhabitat variables affecting fish habitat are related primarily to stream hydraulics and channel morphology including water depth, velocity, substrate (river bottom material), and occasionally cover. The instream flow study conducted for this project quantifies how fish habitat varies according to depth, velocity and substrate characteristics in the river under various flow conditions. Macrohabitat needs are equally important as microhabitat and include items such as sufficient food supply and water quality conditions for aquatic organisms, which are also critical components of the overall Saugus River habitat. For example, microhabitat needs for a longnose dace could be optimized in terms of depth and velocity, however, if water quality conditions are extremely poor, longnose dace will not utilize the habitat.

This section discusses the water quality classification of the Saugus River and the standards established for the designated classification. In addition, previously conducted water quality studies are reviewed in the context of the standards and to determine if water quality conditions are conducive for fish (macrohabitat needs). Previous water quality studies, in some instances, were extensive and included samplings of various parameters including nutrients, water chemistry, bacteria and other contaminants. For purposes of this report, only a subset of the water quality data that directly influence fish habitat are described since these are considered the major indicators of aquatic health. This includes dissolved oxygen concentration and percent saturation, water temperature, and total phosphorus.

7.2 Water Quality Classification

The Massachusetts Surface Water Quality Standards (MSWQS) designate the most sensitive uses for which the surface waters of Massachusetts shall be enhanced, maintained and protected. In addition, the State prescribes minimum water quality criteria required to sustain the designated uses. All surface waters in the State are segmented and classified as one of six classes. The Saugus River is classified as a Class B river, however, its official designation as a Warm Water (Class BWWF) or Cold Water (Class BCWF) Fishery has never been completed (Personal Communication Arthur Johnson, DEP Watershed Management). Although the water quality data probably supports a Warm Water Fishery designation, both are discussed and compared in this report.

Table 7.2-1: Water Quality Classification of the Saugus River

Segment	Water Quality Classification
Saugus River from its source (outlet of Lake Quannapowitt) to the Saugus Iron Works, including the LWSC Diversion Canal	Class B- These waters are designated as habitat for fish, other aquatic life and wildlife, and for primary and secondary contact recreation. Where designated they shall be suitable as a source of public water supply with appropriate treatment. They shall be suitable for irrigation and other agricultural uses and for compatible industrial cooling and process users. These waters shall have consistently good aesthetic value.

The MDEP has developed water quality standards for Class BWWF and BCWF. Shown in Table 7.2-2 is an abbreviated set of water quality criteria that apply to the Saugus River.

Table 7.2-2: Abbreviated Water Quality Criteria for Saugus River

Standard	Class BWWF Criteria	Class BCWF Criteria
Dissolved Oxygen and Percent Saturation	- Shall not be less than **5.0 mg/l** unless background conditions are lower - Levels should not be lowered below **60%** of saturation	- Shall not be less than **6.0 mg/l** unless background conditions are lower - Levels should not be lowered below **75%** of saturation
Water Temperature	Shall not exceed **28.3 degree C**	Shall not exceed **20.0 degree C**
Total Phosphorus	Shall not exceed the site-specific limits necessary to control accelerated or cultural eutrophication	Shall not exceed the site-specific limits necessary to control accelerated or cultural eutrophication

7.3 Past Water Quality Studies

The purpose for listing the criteria in Table 7.2-2 is to compare the water quality data collected on the Saugus River by various entities relative to the criteria. One long-term water quality program and two recent water quality evaluations (1997/1998 and March 2000) have been conducted in the Saugus River Basin. The Saugus River Watershed Council (SRWC) has conducted long-term monitoring in the basin starting in 1992. The Friends of Lake Quannapowitt (FOLQ) have started a long-term monitoring plan that evaluates water quality around the lake since March 2000. MDEP spearheaded the 1997/1998 study, which was an assessment of the North Coastal Watershed, including the Saugus River Basin.

Each of these programs and water quality findings are summarized below. The Saugus River water quality database, collected over the past 10+ years, is extensive. It is not the intent of this report to examine the details of each water quality report, as it would be exhaustive and beyond the needs for this study. Instead, emphasis is placed on select water quality variables and more recent surveys.

The reports cited below were reviewed to determine if 1) a quality assurance/quality control (QA/QC) program was implemented to substantiate the water quality findings and 2) if study results reflected similar trends. A rigorous QA/QC program was implemented for the MDEP study, however, reports for the remaining studies did not note such a program. The findings contained in all three water quality studies appear to reflect the same general trends throughout the basin. For example, the MDEP report noted “the volunteer-based monitoring corroborates the findings of the DEP and Hudsonia report”. In summary, we cannot verify the water quality results, however, based on a review of the water quality trends and findings, the study results appear reasonable.

All water quality sampling locations, for all three studies, are shown on Figure 7.3-1.

7.3.1 Friends of Lake Quannapowitt

The Friends of Lake Quannapowitt have been collecting water temperature, dissolved oxygen (DO), conductivity, salinity and secchi disk[15] data since March 2000. Data was provided by Doug Heath, EPA (data is also available on Friends of Lake Quannapowitt web page- http://www.wakefield.org/folq/folq.htm). Sampling locations are described in Table 7.3.1-1.

Table 7.3.1-1: Friends of Lake Quannapowitt Sampling Locations

Station Code	Description of Sampling Location
FOLQ1	Lake Quannapowitt outfall, just upstream of outlet
FOLQ2	At Berm, End of Willard Street, just south of the Lord Wakefield Inn.

The berm, at sampling location FQLQ2, functions to reduce phosphorus input to the lake through slow-sand filtration (although its efficiency has been questioned). Flow estimates at the Lake Quannapowitt dam and near the berm (where a V-notched weir is located) are approximated from standard weir equations. The sampling protocol includes taking spot measurements approximately once a week primarily between 8:00 am and noon.

The Lake Quannapowitt drainage area is heavily urbanized. The 254-acre lake is classified as eutrophic due to excessively high nutrient loadings (presumably phosphorus and nitrate), which results in large growths of algae in the summer. The algae become oxygen demanding when they die and settle to the bottom, resulting in low DO concentrations. The lake is also highly turbid, and has low transparency as confirmed by Secchi disk readings (<3 feet, based on data collected by FOLQ). Shown in Figure 7.3.1-1 are the DO concentrations taken at the outfall and berm from March 2000 to current. As the plot shows, DO concentrations are below the Class BWWF standard at the berm location, and above the standard at the outfall.

It should be noted that DO sampling was typically conducted in the morning (after 8:00 am) or afternoon. DO concentrations commonly vary over a 24-hour cycle, as aquatic plants emit oxygen (photosynthesis) during the day and respire, or use oxygen, at night (produce CO_2). The lowest DO levels typically occur at dawn, which is earlier than the sampling times for this study. It is suspected that DO concentrations at the outfall would be lower at dawn.

Another indicator of water quality is to compare the amount of DO possible in water of a given temperature and the amount of DO actually recorded during sampling. This comparison results in a measure of the percent saturation of the water- how much is present in a sample compared to ideal conditions. Ideally an 85% or better level would be desirable. Shown in Figure 7.3.1-2 are the DO percent saturation results taken at the berm and outfall. Similar to DO, the percent saturation at the berm was below the Class BWWF and BCWF standard and percent saturation was above the standards at the outfall. Supersaturation, when the percent saturation is greater than 100%, occurred below the outfall during the summer 2000. Supersaturation occurs primarily during daylight hours when plants are emitting oxygen. The inverse occurs at night, as plants respire and percent saturation levels are lowest at dawn.

[15] Secchi disk measurements are taken near the north end of the Quannapowitt Yacht Club.

Shown in Figure 7.3.1-3 are water temperature data collected at the berm and outfall. In most instances, the water temperatures were below the Class BWWF 28.3 °C standard during the spring months (March through May), but greater than the Class BCWF 20.0°C standard during the summer (June through August).

7.3.2 North Coastal Watershed 1997/1998 Water Quality Assessment Report

Water Quality

In 1997/1998 MDEP conducted an extensive water quality assessment of the North Coastal Basin, including the Saugus River Basin. The purpose of the study was to collect background water quality data, and to focus on areas of resource protection and remediation activities. The MDEP sampling locations are listed in Table 7.3.2-1 and depicted in Figure 7.3-1 (Reference: Water Quality Assessment of Gloucester Harbor, The North, Salem/Peabody, The Saugus River, Smallpox Brook, Salisbury).

Table 7.3.2-1 MDEP Sampling Locations - Chemical Sampling Sites

Station Code	Description of Sampling Location
MDEP1	River Mile 4.2, east of the Saugus River Iron Works, due west of the end of Bridge Street
MDEP2	River Mile 5.7, upstream/west at Route 1
MDEP3	River Mile 9.7, upstream/north at Salem Street
MDEP4	River Mile 13.2, outlet of Lake Quannapowitt, downstream/east of Main Street

Stream samples were collected and evaluated for water chemistry (dissolved oxygen, temperature, pH, etc), nutrients (phosphorus, etc), bacteria (fecal coliform), and macroinvertebrates. Water quality sampling extended over the period: June, July, September, October, November, 1997 and January, March 1998. The parameters sampled in the Saugus River Basin varied, in some instances, by location and sampling date.

DO data collected along the Saugus River was compared to the DO criteria for cold and warm water fisheries as shown in Figure 7.3.2-1. DO measurements taken below the Lake Quannapowitt outlet were typically below the DO standard while samples collected from other locations typically meet or exceed BWWF DO standards. Similar to the FOLQ study, DO sampling generally occurred between 8:00 am and noon. Again, sampling was not conducted at dawn when DO levels are expected to be lowest. DO saturation levels were also below the 60% saturation standard at the Lake Quannapowitt outlet during the summer months but above the standard at downstream locations as shown in Figure 7.3.2-2.

Water temperatures collected during the survey were all below the Class BWWF criteria, while some samples were slightly above the Class BCWF criteria, as shown in Figure 7.3.2-3.

Phosphorus is a nutrient essential for growth that can play a key role in stimulating aquatic growth in lakes and streams. High phosphorus loading can result in excessive algae growths, which in turn become oxygen demanding when they die. The State of Massachusetts does not have a numerical standard for phosphorus, but there is a widely recognized limit of 0.05 mg/l for Class B waters. Shown in Figure 7.3.2-4 are the total phosphorus results, which are typically above the 0.05 mg/l recognized limit. It is not surprising that total phosphorus levels are highest in the upper watershed, particularly due to eutrophication at Lake Quannapowitt and Reedy Meadows.

Macroinvertebrate Sampling

In addition to testing water chemistry, the MDEP also conducted macroinvertebrate sampling at various locations in the North Coastal Basin, including the Saugus River. Aquatic macroinvertebrate[16] sampling provides an indicator, in addition to water chemistry, of the river's health. These organisms also serve as food sources to fish.

Aquatic macroinvertebrates were collected from selected sites within the North Coastal Basin by kick-sampling. Ten individual (two in the Saugus River) kicks taken within a 100 m reach of the selected stream were composited, representing a sample area of 2 m^2. Habitat quality was scored at each sampling location following a habitat assessment procedure modified from Plafkin, et al (1989). At sites where the kick-sampling methodology could not be applied a qualitative sample was collected by kicking bottom sediments, jabbing under banks, and sweeping through submergent and emergent vegetation.

Specimens were identified to family so that RBP[17] II metrics (Plafkin et al. 1989) could be calculated. No sub sorting was done for qualitative samples. Instead, specimens were selected from the sample only if they were different from what had already been removed, thereby given an indication of the diversity within the sample.

Macroinvertebrate sampling was conducted in the Saugus River at the locations shown in Table 7.3.2-2.

Table 7.3.2-2 MDEP Sampling Locations - Macroinvertebrate Sampling Sites

Station Code	Description of Sampling Location
MDEP1	River Mile 4.2, east of the Saugus River Iron Works, due west of the end of Bridge Street (used as reference site)
MDEP2	River Mile 5.7, upstream/west at Route 1
MDEP3	River Mile 9.7, upstream/north at Salem Street

At sampling sites MDEP1 and MDEP3, macroinvertebrates were collected with kick-samples, whereas at sampling site MDEP2 only a qualitative assessment was conducted. Taxa were identified at the two sampling locations as shown in Table 7.3.2-3

[16] Definition: Aquatic Macroinvertebrates - broadly defined as freshwater (aquatic) animals large enough to be seen by the naked eye (macro) and lacking a backbone (invertebrate).
[17] RBP - rapid bioassessment protocols (see Glossary of Terms for Definition)

Table 7.3.2-3 Taxon in the Saugus River

Taxon	Sampling Site MDEP3	Sampling Site MDEP1
Hydrobiidae	0	1
Physidae	1	1
Enchytraeidae	0	1
Tubificidae	2	0
Naididae	1	3
Asellidae	20	2
Gammaridae	24	10
Hydropsychidae	49	47
Glossosomatidae	0	9
Tipulidae	1	0
Simuliidae	1	1
Chironomidae	3	23
Empididae	1	0
TOTAL	103	98
HBI[18]	5.6	4.7
FAMILIES	10	10

Sampling site MDEP3 was heavily dominated by the filter-feeding Hydropsychidae. The MDEP report states that this is probably an indication that the combined effects of an upstream impoundment (Diversion Dam) at the Sheraton Golf Course, runoff from the highway, and erosion within the sample reach which contribute to a high particulate loading that these organisms can exploit as a food source.

Sampling site MDEP1, the most downstream site on the Saugus River, provided the best lotic macroinvertebrates and fish habitat of all North Coastal Basin sites. The report notes that the river channel appeared to have an unaltered pattern and there was a wide vegetated zone on both banks providing a good buffer. The dominance of cobble and boulder in this reach provided excellent substrate for macroinvertebrates.

As noted above, the level of impairment is based on a reference condition. MDEP notes that distinguishing grades of impairment from the findings is difficult or impossible because no suitable reference site was found. Alewife Brook in Gloucester was selected to serve as the reference for the North Coastal Basin. At the time sampling was conducted (July 1997), however, there was no water flowing in the channel between its wetland headwaters and Babson Reservoir. Though not well suited to serve as reference sites because of the extent of development adjacent to, and upstream from them, the Frost Fish Brook site in Danvers and the Saugus River site in Saugus were selected as the best alternative references. The impairment level analysis resulted in the following findings:

[18] HBI- Hilsenhoff biotic index value. See Glossary of Terms, Conversions and Definitions for Definition of HBI.

The analysis conducted by MDEP resulted in ranking the MDEP3 sampling site as moderately impaired when compared against the reference site in the Saugus River (MDEP1) and non/moderately impaired when compared to the Frost Fish Brook site. Similarly, the MDEP1 site was ranked between nonimpaired to moderately impaired relative to the Frost Fish Brook site. Sampling site MDEP2 was not ranked.

7.3.3 Saugus River Watershed Council

The Saugus River Watershed Council (SRWC) and its volunteer group began water quality testing of the Saugus River and its tributaries in 1992. The SRWC publishes an annual report that summarizes their findings. The monitoring program stemmed from the original baseline water quality study conducted by Hudsonia Limited of New York.

Monitoring is conducted monthly for DO, pH, turbidity, air/water temperature, and fecal coliform bacteria. In addition, qualitative observations are also recorded on general site conditions, flowage, weather conditions, riverbank stability, flow, macrophytes and wildlife. The intent of these studies is to establish baseline information, on which to build a watershed management plan and to identify poor water quality areas for remediation.

Based on their years of sampling and observation, SRWC notes a few consistent themes in their reports as summarized below:

- High bacteria levels are typically found after high rainfall events. SRWC believes this is a function of non-point source pollution entering the river from stormwater runoff. There are also specific fecal coliform “hot-spots” on the river, which display high bacteria counts regardless of weather conditions.
- The river has DO levels below the 5 mg/l standard for a Class BWWF, most consistently in the shallow and warm freshwater sections of the river.
- Water temperatures in the Saugus River, particularly during the summer are generally high. Water temperatures are typically higher in the upper watersheds versus the lower watershed. SRWC suspects this is the result of wide expansive shallow areas such as Lake Quannapowitt, and Reedy Meadows in the upper watersheds that are heated by air temperatures.
- SRWC indicates that eutrophication, high water temperatures, non-point source pollution, low flows, and localized fecal coliform contamination appear to be the major factors influencing the poor water quality of the Saugus River.
- SRWC has observed fish kills below the LWSC Diversion Dam due to stranding as discharges are reduced.
- SRWC noted that high nutrient levels occur consistently throughout the year.

A full analysis of the data collected since 1992 is beyond the scope of this study, however, the most recent 1998 data was evaluated here. Shown in Table 7.3.3-1 are the SRWC sampling locations in 1998, which represents only mainstem sampling (note that tributary sampling is also conducted). The approximate sampling locations are shown in Figure 7.3-1.

Table 7.3.3-1 SRWC Sampling Locations in 1998

Station Code	Description of Sampling Location
SRWC1	Below Lake Quannapowitt outfall
SRWC2	At the LWSC Diversion Dam, in the heapond
SRWC3	Camp Nihan Footbridge
SRWC4	Breakheart Reservation at old mill site
SRWC5	Route 1
SRWC6	Prankers Pond at footbridge
SRWC7	Saugus Ironworks
SRWC8	Railroad Bridge
SRWC9	Boston Street Bridge *(located in tidal reach)*

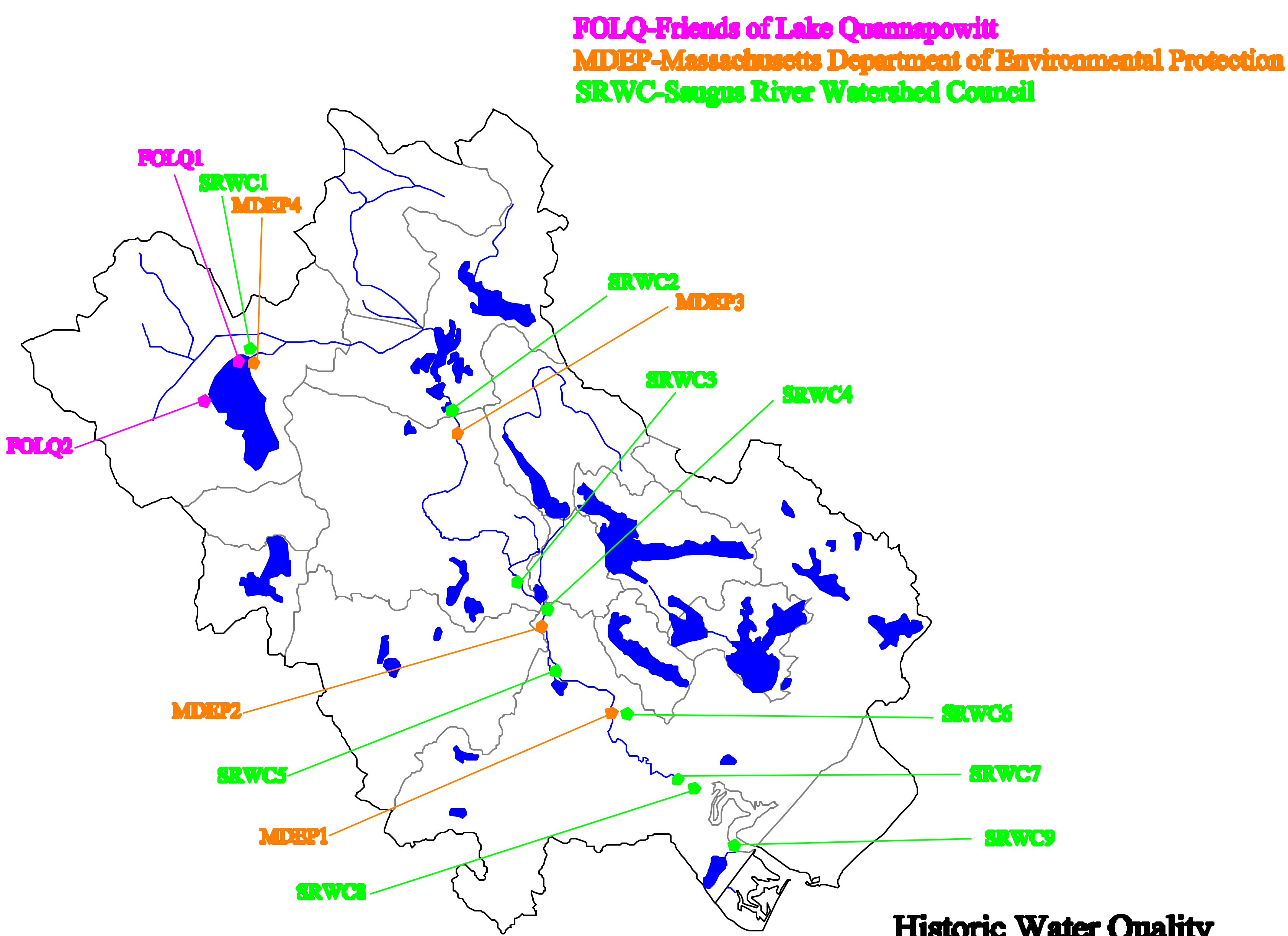
Shown in Figure 7.3.3-1 are monthly DO concentrations at the various stations along the Saugus River. As expected, DO concentrations were typically lowest in the summer, and increased somewhat during the fall/winter period. The trend is reasonable as colder water temperatures can hold more dissolved oxygen than higher temperatures. There were many instances where DO levels were below Class BWWF and Class BCWF standards. Low DO concentrations were observed consistently throughout the year at Camp Nihan (SRWC3) and at the Railroad Bridge (SRWC8).

Shown in Figure 7.3.3-2 are water temperature data recorded at the same monitoring stations. Water temperatures were highest in August and September, exceeding the Class BCWF standard at many stations, but all stations were within the Class BWWF standard.

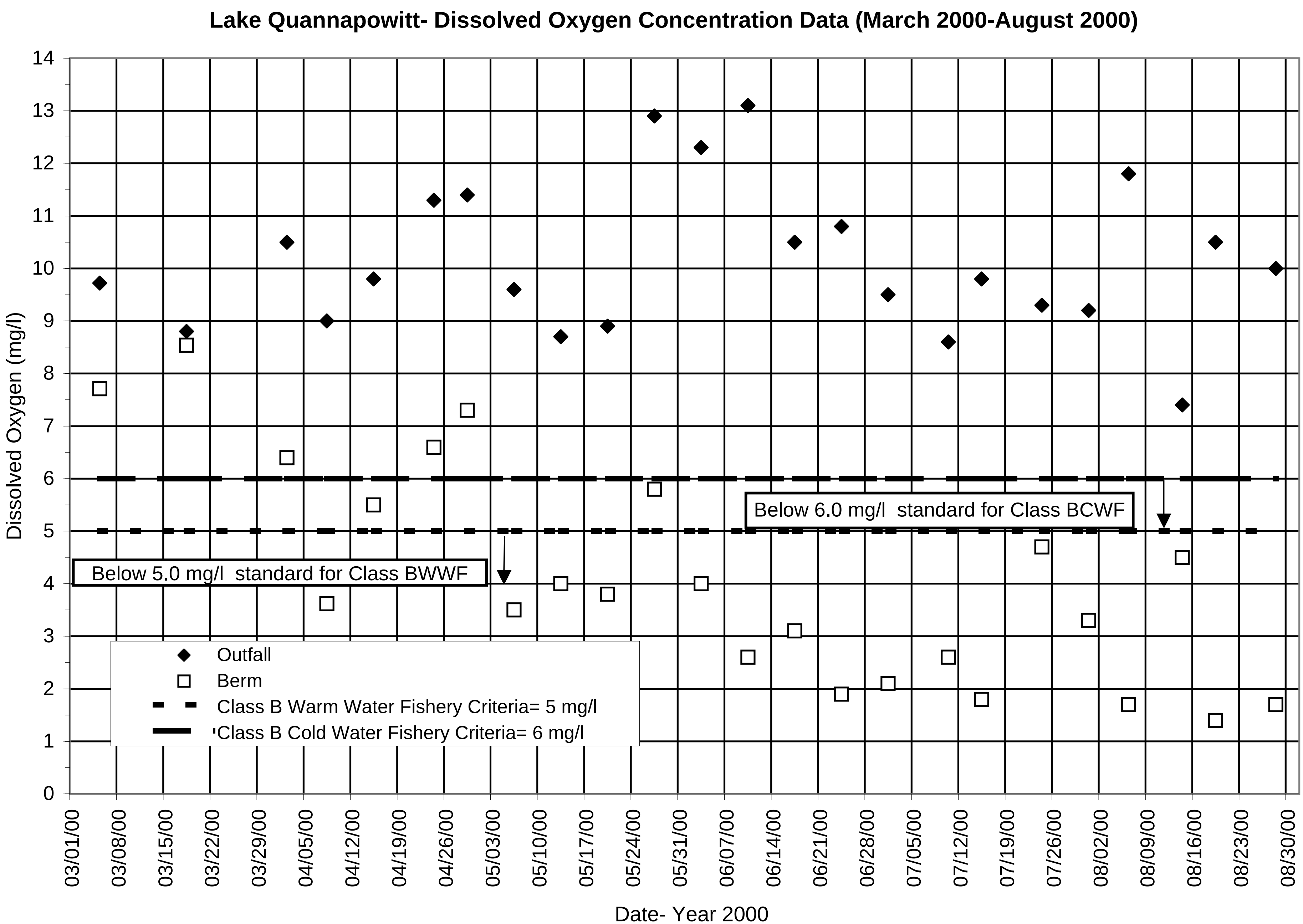
Other factors that could affect water quality include chemicals or fertilizers used on two golf courses (Sheraton and Cedar Glen) located in close proximity to the Saugus River. Runoff from these areas could result in elevated nutrient levels (phosphorus and nitrogen) in the Saugus River. The water quality programs to date have not been designed to determine what, if any, impact golf course fertilizing has on water quality.

At the request of the SRWC, included in Appendix G is the 2001 water quality report.

In summary, the river is considered a warm-water fishery due to high water temperatures, particularly during the summer period. Dissolved oxygen concentrations are below the Class BWWF standard of 5.0 mg/l at various locations in the basin- with most violations occurring in the summer period when water temperatures are high and flow is low. Most water temperatures are within the Class B standard of 28.3 °C, but are too high to be within the Class B coldwater standard of 20.0 °C. The Saugus River Watershed Council (SRWC) has been the major group collecting water quality data in the basin since 1992. Over the years, they have noticed a progressive improvement in water quality. In general, the water quality in the basin is considered fair, although it is improving. In 2001, when the LWSC maintained a continuous flow below the Diversion Dam, the SRWC noticed improved water quality conditions- potentially as a result of maintaining a continuous flow, particularly during the summer. Implementation of the flow recommendations made later in this document may facilitate improvement in overall water quality. Maintaining the current SWRC water quality monitoring plan when (and if) the recommended flows are provided will shed further light on whether water quality conditions continue to improve.

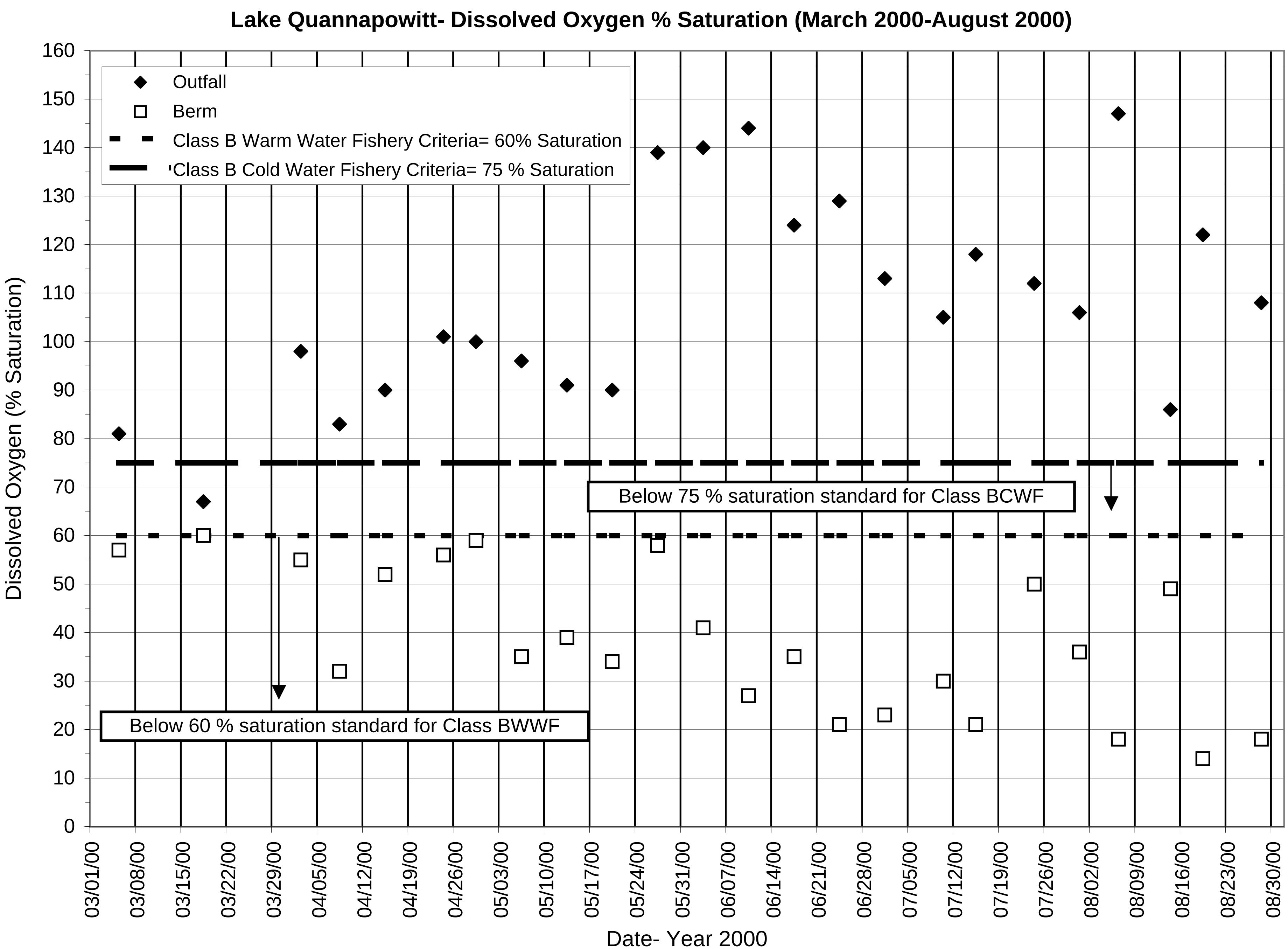


Historic Water Quality Sampling Locations Approximate Scale 1=100,000 FIGURE 7.3-1



Data Collected by The Friends of Lake Quannapowitt

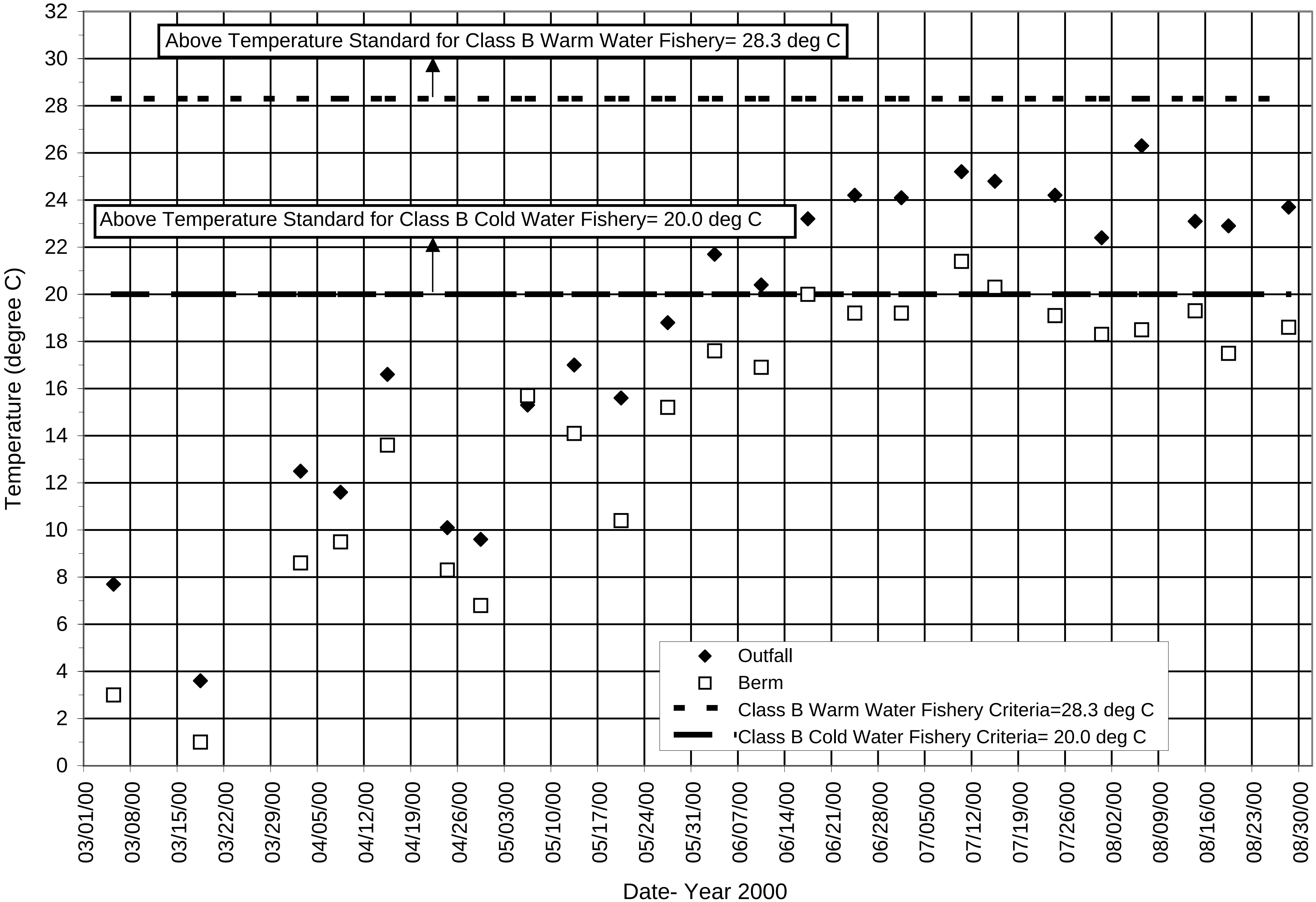
FIGURE 7.3.1-1



Data Collected by The Friends of Lake Quinnapowitt

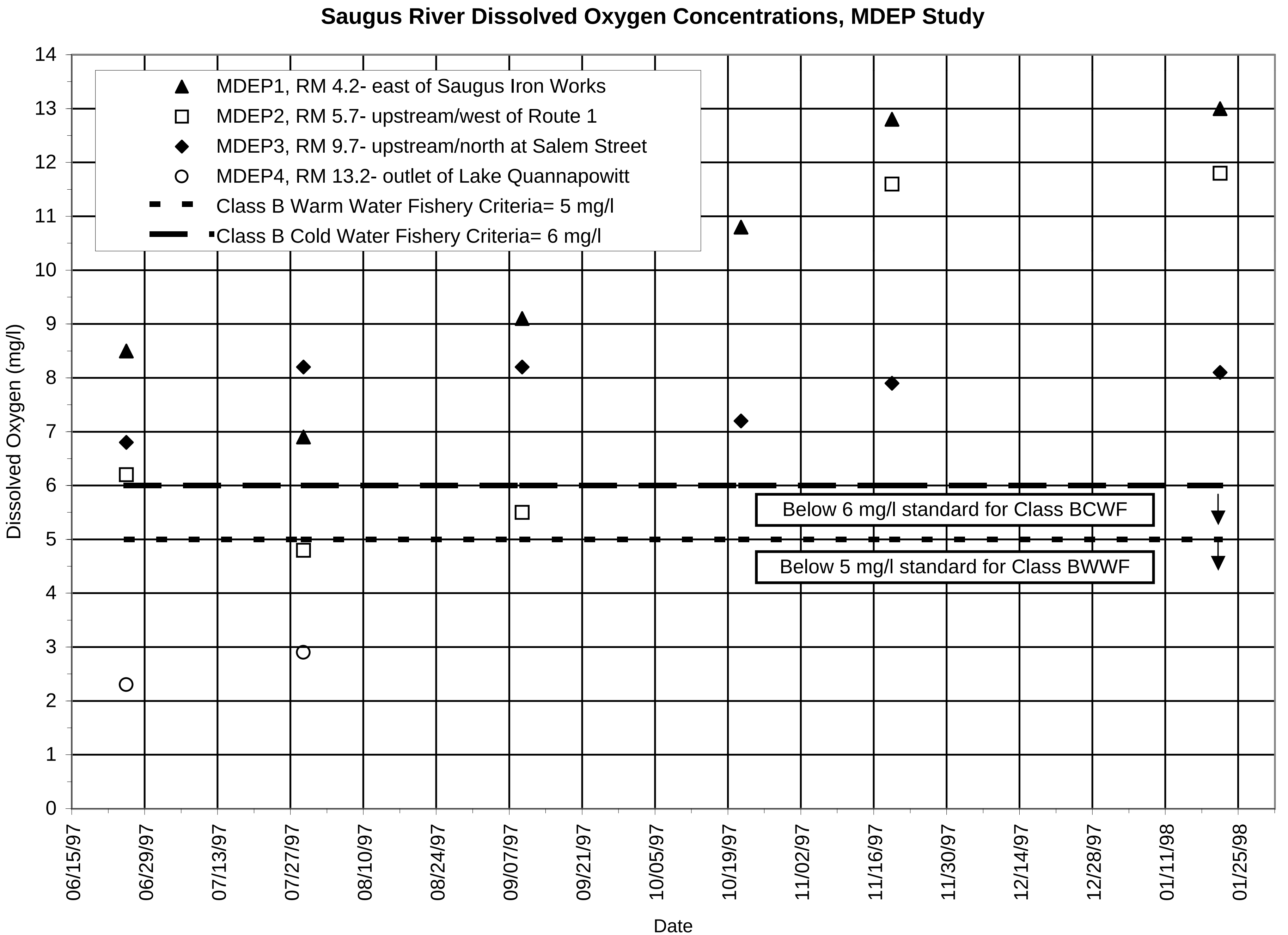
FIGURE 7.3.1-2

Lake Quannapowitt- Water Temperature Recorded at Berm and Outfall (March 2000-August 2000)



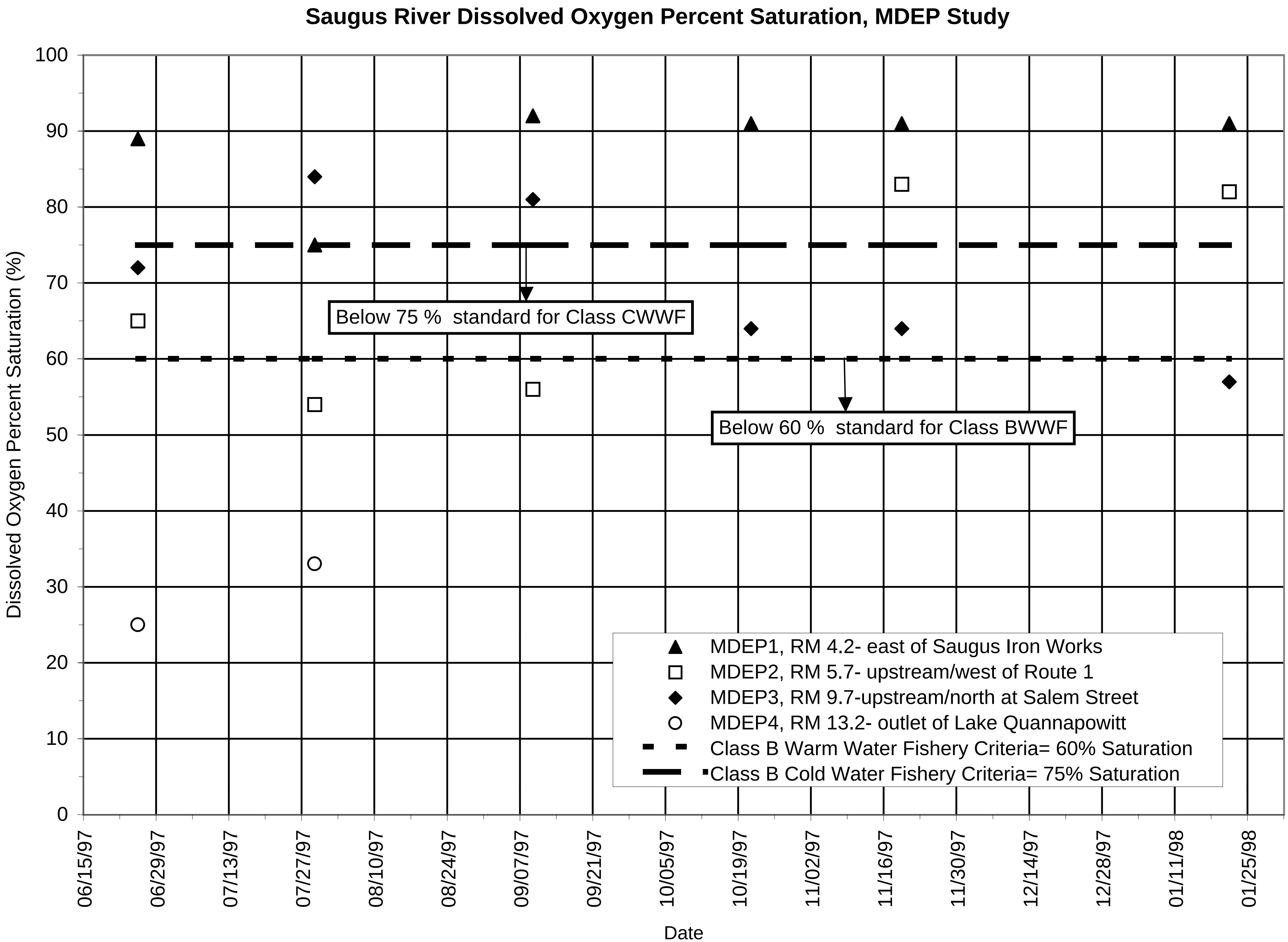
Data Collected by The Friends of Lake Quannapowitt

FIGURE 7.3.1-3



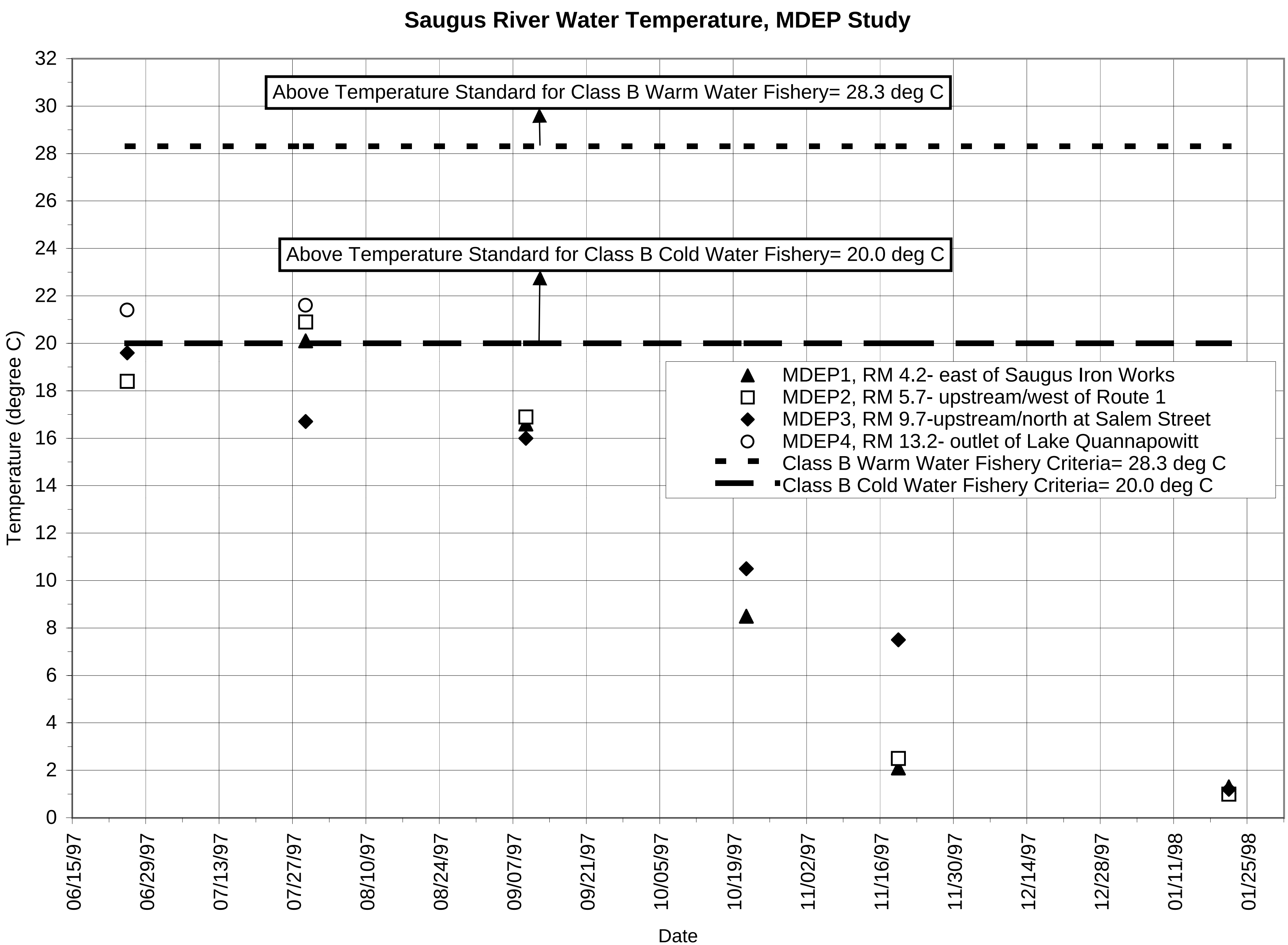
Data Collected By MDEP

FIGURE 7.3.2-1



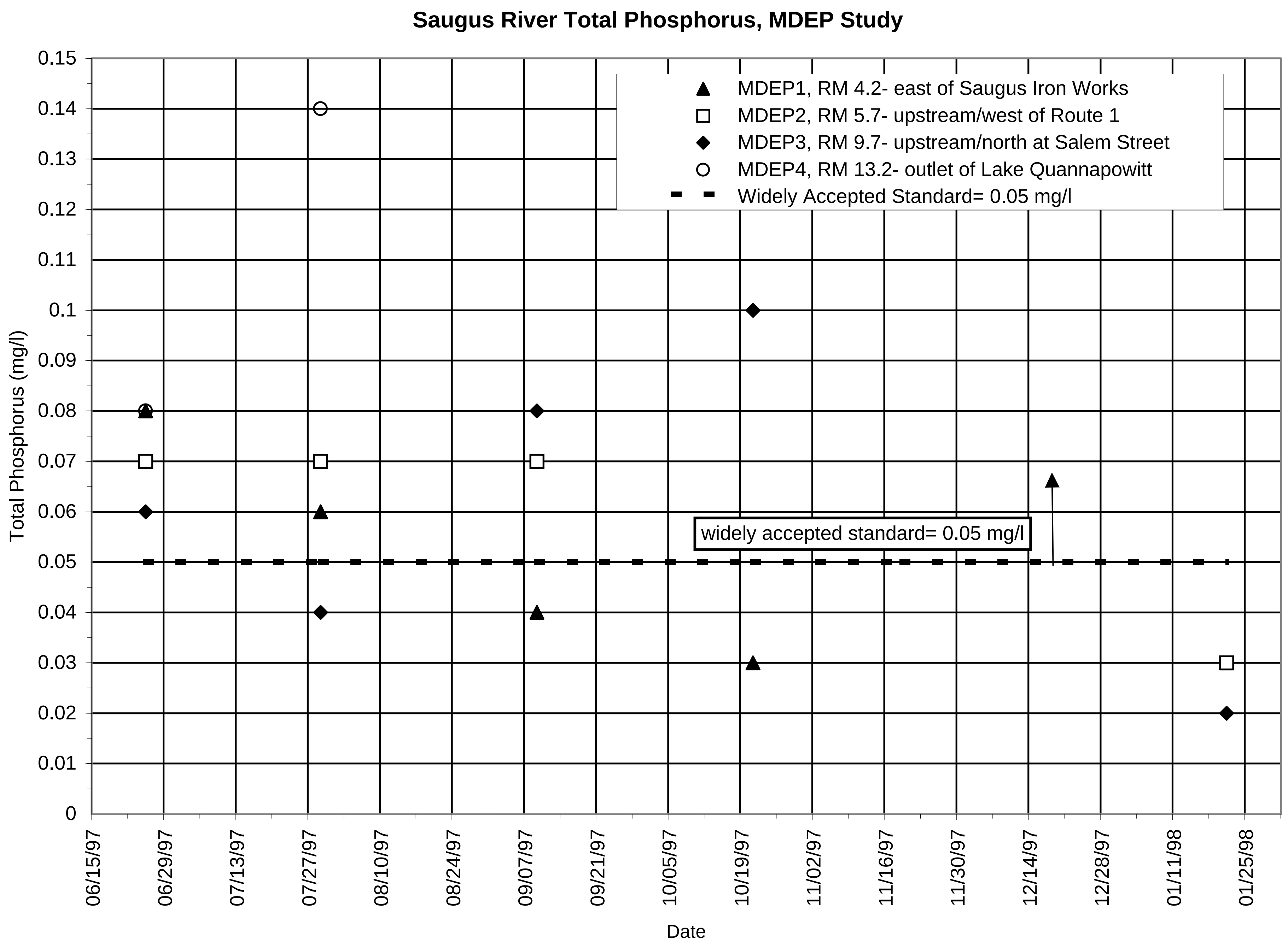
Data Collected by MDEP

FIGURE 7.3.2-2



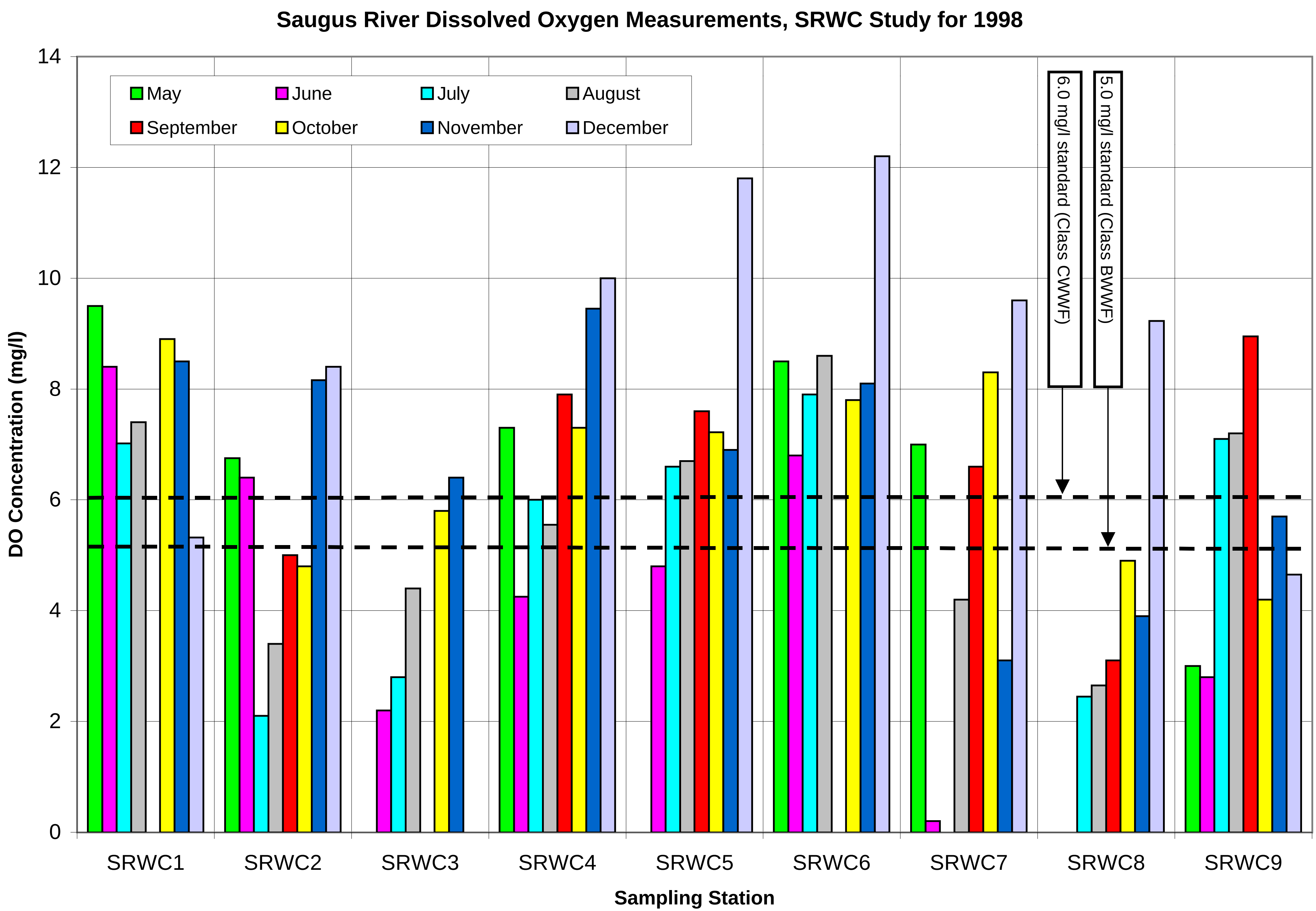
Data Collected by MDEP

FIGURE 7.3.2-3



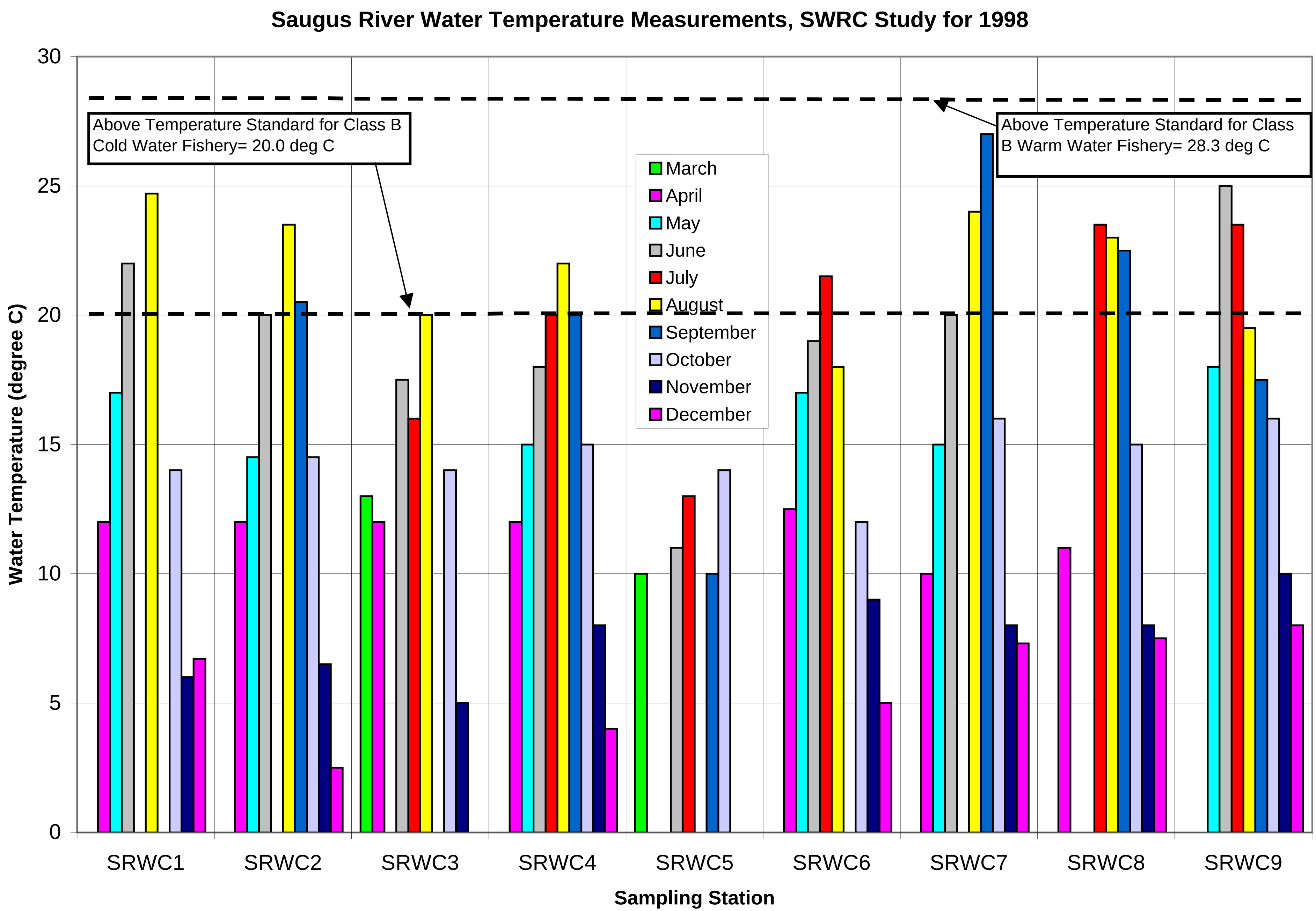
Data Collected by MDEP

FIGURE 7.3.2-4



Data Collected by SRWC

FIGURE 7.3.3-1



Data Collected by SRWC

FIGURE 7.3.3-2

8.0 Habitat Mapping Results

8.1 Overview

In order to conduct an Instream Flow Study, an understanding of the Saugus River aquatic habitat is needed. Thus, a habitat map of the Saugus River from the LWSC Diversion Dam to the head of tide, at the Saugus Ironworks, was created. Developing a habitat map entails walking the river and denoting various physical features of the river. Typically, the river is broken into mesohabitat units such as riffles, runs or pools by visual observation of the water surface and river depth. Within each of these habitat units, further physical information (microhabitat) is recorded during the walkover such as the length and width of the habitat unit as well as the depth, approximate velocity, substrate size, overhead cover, and instream cover. These physical features, in addition to other factors such as water quality, have an impact on habitat availability for fish and other aquatic organisms. Developing a habitat map provides information on the type and quantity of various habitat units present in the river.

Habitat mapping was conducted from July 18–21, 2000. On July 18, 2000, the walkover consisted of members of the Saugus River Watershed Council (SWRC-Joan LeBlanc, Kathy Wyrnn), Massachusetts Department of Environmental Management (MDEM- Mike Gildesgame, Linda Marler), Massachusetts Executive Office of Environmental Affairs (EOEA- Larry Gil) and Gomez and Sullivan (GS- Paul Piszczek, Mark Wamser). EOEA, MDEM and GS completed the remaining habitat mapping on July 19-21.

Flow in the Saugus River was controlled by a sluice gate at the Diversion Dam. Prior to the walkover, the LWSC was contacted to ensure that flow was released through the gate to the Saugus River. Maintaining a continuous release ensured that riffles, runs and pools could easily be identified. Gate openings and flow records at the Saugus River USGS gage during the walkover dates are shown in Table 8.1-1.

Table 8.1-1: LWSC Gate Opening and USGS Gage Flows During Walkover

Date	LWSC Gate Opening	USGS Gage- Average Daily Flow
July 18, 2000	6 inches	25.7 cfs (provisional)
July 19, 2000	6 inches	29.0 cfs (provisional)
July 20, 2000	6 inches	27.0 cfs (provisional)
July 21, 2000	2 inches	18.2 cfs (provisional)

Shown in Figure 8.1-1 are the hourly flow data recorded at the Saugus USGS Gage during the 4-day habitat mapping. The flow range during the walkover was greater than that normally experienced during the summer months under both regulated and unregulated conditions. The flow was more typical of spring and fall flows, and was about double the flows occurring prior to the walkover.

8.2 Data Collected During Habitat Mapping

A habitat matrix was completed for the five-mile reach under study as shown in Appendix H. In addition, shown in Appendix H is a series of maps depicting the break points of habitat units.

The following data was recorded at each habitat unit during the walkover, which represents the headings to the habitat matrix in Appendix H.

- Habitat Map Location- this refers to the habitat unit (riffle, run or pool). The first riffle in the downstream direction is denoted RF-1, second riffle RF-2, etc.
- Reach Length- this refers to the length of each riffle, run or pool. Reach lengths were measured with a hip chain or 300' tape measure. A USGS 1:25,000-scale, 15 minute quadrangle map was used to estimate reach lengths that were extensive (> 1,000 feet long) or covered by overly dense vegetation.
- River Width- the river width perpendicular to flow within each habitat unit was measured with a tape. Measurements were taken near the mid-section of each habitat unit.
- River Depth- a range of river depths within each habitat unit was measured with a pre-marked wading rod.
- River Velocity- a range of river velocities was approximated within each habitat unit based on visual observation.
- Substrate- Substrate within each habitat unit was characterized by visual observation, or in deep areas, by foot or feel. Substrate was described as follows: detritus, muck, silt, sand, gravel, cobble, small boulder or large boulder. Because substrate size can vary within a habitat unit, a percentage was assigned by visual observation such as 60% cobble, 30% gravel and 10% small boulder.
- Overhead Cover- overhead cover describes the amount of tree or vegetation canopy above the river, which was defined as low, medium or high based on visual observation.
- Velocity Refuge Areas- this refers to areas where fish could escape high velocity areas of the river such as areas near submerged logs or boulders. Similar to overhead cover, this was defined as low, medium or high based on visual observation.
- Remarks- includes general information such as observed fish, landmarks, culvert locations, etc.
- Photos- photographs of each habitat unit were taken from the approximate downstream end of each habitat unit.

8.3 General Overview of Saugus River Habitat

The five-mile reach between the Diversion Dam and Saugus Ironworks flows through diverse land uses including residential, commercial, wetland, forest, and recreational (golf courses and Metropolitan District Commission's Breakheart Reservation), and includes a variety of substrate and cover characteristics. The Saugus River is characterized primarily by run habitat throughout much of its length from the Diversion Dam to the head of tide. Channel gradients are lower in the upstream reaches compared to the downstream reaches, and are highest between Elm Street and the head of tide. Pools and riffles are limited throughout the river, with pool depths ranging from three to five feet deep. Table 8.3-1 shows the habitat delineations and associated lengths throughout the Saugus River.

Table 8.3-1. Type and Length of Habitat Units in the Saugus River

Habitat Type	No. of Habitat Units	Cumulative Length of Habitat Units (feet : miles)	Length of Habitat Units Relative to Total River Length (%)
Riffle	27	1,529 : 0.30	5.7%
Run	65	24,875 : 4.71	93.0%
Pool	9	333 : 0.06	1.3%
Total	101	26,737 : 5.07	100%

The extreme upper reach of the Saugus River (Diversion Dam to Salem Street) consists of cobble/gravel-based riffles and sand/silt-based runs. However, low-gradient, run habitat predominates the river channel between Salem Street and Water Street (Route 129). The channel typically ranges from 20 to 30 feet wide and 2.0 to 4.0 feet deep, and includes an abundance of snags and overhanging vegetation. Substrates consist primarily of sand, silt, and muck, with interspersed detritus and gravel.

Run habitat predominates the Saugus River between the Cedar Glen Country Club on Water Street and U.S. Route 1, and the river flows through extensive wetland areas. The channel is composed of sand and silt, and ranges from 2.5 to 3.0 feet deep and 15.0 to 28.0 feet wide. Bank vegetation is dense, and primarily herbaceous; overstory occurs only in the lowermost section (near the upstream side of Route 1). The channel is distinct, but its bank full capacity is frequently exceeded, thereby causing overflow into the wetland. There is a short rather shallow riffle at the Camp Nihan footbridge.

Low-gradient, run habitat characterizes the river from U.S. Route 1 to the Saugus town limits, with a predominance of sand and gravel substrate. However, the river transitions to progressively higher gradient downstream, with an increase in coarse substrates such as gravel and cobble. The channel experiences an increased frequency of alternating riffles and runs, but maintains a relatively consistent width of approximately 20 feet to the head of tide.

Shown in Table 8.3-2 are the habitat types along with the ranges of river widths.

Table 8.3-2. Distribution of stream width relative to habitat type in the Saugus River

Habitat Type	Frequency	Range of Widths (feet)
Run	3	0-9
	18	10-19
	38	20-29
	5	30-39
	1	40-49
Riffle	0	0-9
	14	10-19
	12	20-29
	1	30-39
	0	40-49
Pool	0	0-9
	1	10-19
	4	20-29
	2	30-39
	2	40-49

8.4 Meetings and Transect Selection

On November 13, 2000, a meeting was held with Mark Wamser and Paul Piszczek (Gomez and Sullivan), Dave Armstrong (USGS), Cindy Delpapa (Massachusetts Department of Fisheries, Wildlife and Environmental Law Enforcement (DFWELE), Linda Marler (MDEM), Larry Gil (EOEA), Todd Richards (MDFW), Joan LeBlanc (SRWC) and Rick Dawe (LWSC) to discuss transect selection. Based on the habitat mapping, Gomez and Sullivan made preliminary selections of two river reaches where transects would be located. The reaches were located immediately below the LWSC Diversion Dam and below Route 1 (near Staples). The reaches contained primarily riffle and run habitat. Substrates consisted primarily of sand, gravel, cobble and some boulders. The river gradient was greater in these reaches, relative to the middle Saugus River (from Salem Street to Route 1). It was noted in the meeting that the middle Saugus River is extremely sluggish (slow moving run) and the substrate is primarily silt, sand and muck. Although the reaches selected were not characteristic of the longer middle Saugus River, parties recommended that habitat be quantified in these higher gradient reaches. Meeting participants indicated that if the habitat requirements in these reaches were satisfied (in terms of flow needs), then it would be sufficient for maintaining habitat needs in the middle Saugus River as well.

Given the group’s consensus, on May 17, 2001, Gomez and Sullivan placed transects in the reach between the LWSC Diversion Dam and the Route 128 bridge (hereafter referred to as the “Diversion Dam Reach”). Transects were also placed below Route 1 near Staples (hereafter referred to as the “Staples Reach”). Shown in Figure 8.4-1 are the approximate reach locations. All transects were flagged with survey tape for the large group site visit on May 24, 2001.

On May 24, 2001, the following individuals visited the transect locations: Linda Marler (MDEM), Larry Gil and Rebecca Cassotis (EOEA), Deb Olstein (EOEA Riverways), Janet Regan (NPS, Saugus Ironworks) Tom Lamonte and Duane LeVangie (MDEP), Cindy Delpapa (DFWELE), Rick Dawe (LWSC), Ken Burnham (LCWD) and Mark Wamser (Gomez and Sullivan). Although some parties could not make the field visit, they were informed of the reach locations and could reference the survey flagging for the specific transect locations. Mark Wamser provided an overview of the study as well as the purpose and goals. Some participants visited the transect locations. In the end, no changes to the transect locations were recommended during the site walkover.

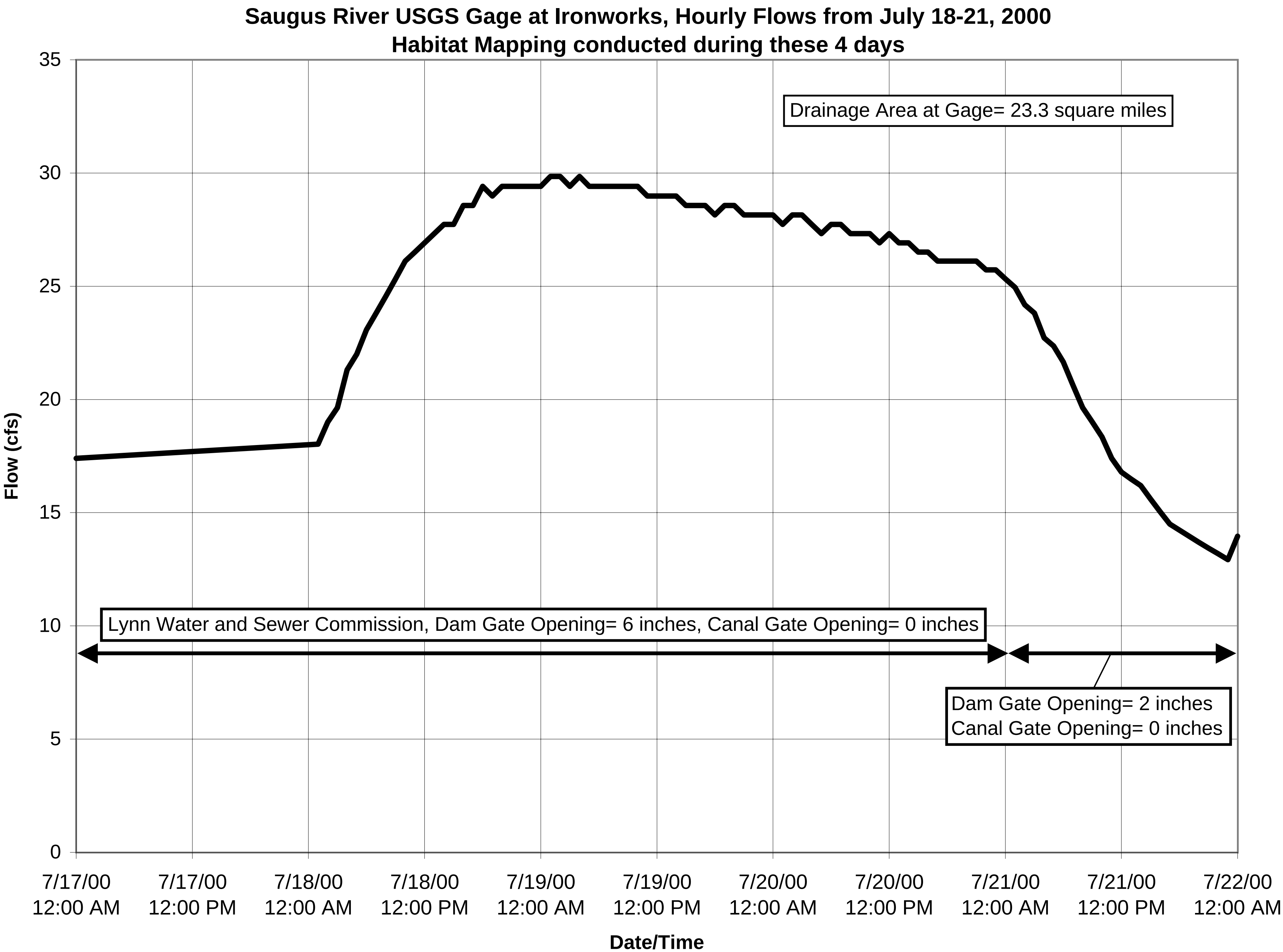
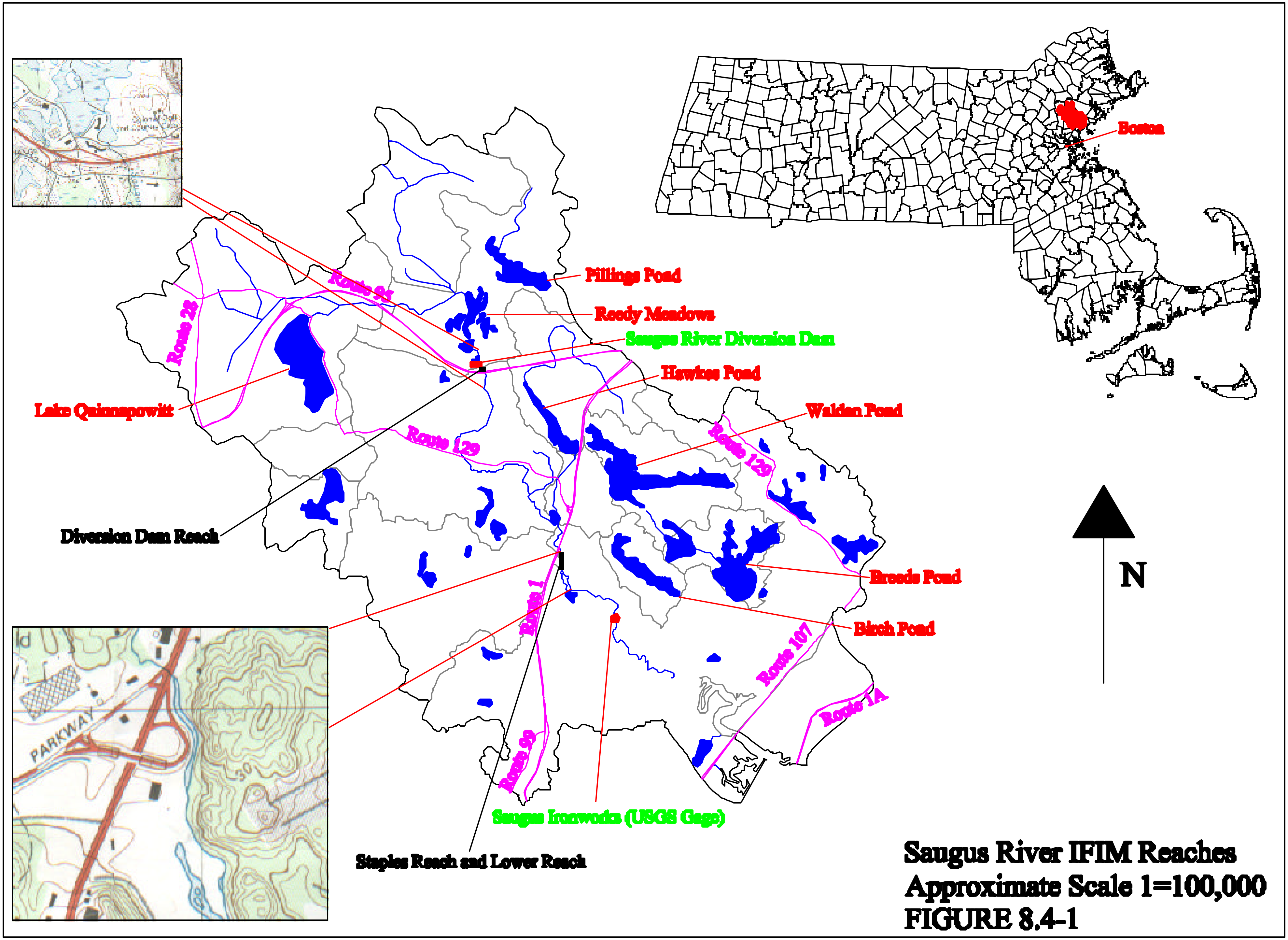

Saugus River USGS Gage at Ironworks, Hourly Flows from July 18-21, 2000
Habitat Mapping conducted during these 4 days
Drainage Area at Gage= 23.3 square miles
Lynn Water and Sewer Commission, Dam Gate Opening= 6 inches, Canal Gate Opening= 0 inches
Dam Gate Opening= 2 inches
Canal Gate Opening= 0 inches
Flow (cfs)
35
30
25
20
15
10
5
0
7/17/00 12:00 AM
7/17/00 12:00 PM
7/18/00 12:00 AM
7/18/00 12:00 PM
7/19/00 12:00 AM
7/19/00 12:00 PM
7/20/00 12:00 AM
7/20/00 12:00 PM
7/21/00 12:00 AM
7/21/00 12:00 PM
7/22/00 12:00 AM
Date/Time

FIGURE 8.1-1



Saugus River IFIM Reaches
Approximate Scale 1=100,000
FIGURE 8.4-1

9.0 Fish Species and Habitat Suitability Index Curves

9.1 Historical Fish Species Present in the Saugus River Basin

The history of the Saugus River system mirrors the history of most southern New England Rivers. Archaeological investigations in the basin confirm extensive Native American habitation including one of the four oldest known sites in the Commonwealth. The river has been dammed for commercial purposes since the 1630's starting with the Saugus River Ironworks (now a National Historic site) and saw mills progressing to a series of mills and commercial endeavors using the river for power and waste disposal.

To gain a better understanding of the historical fish species of the Saugus River, Janet Regan of the National Park Service (NPS) at the Saugus Ironworks translated into modern English a document entitled "Saugus in the Seventeenth Century- From New England's Prospect" by William Wood, 1635.

William Wood wrote in 1635 that a number of species were present in the tidal portion of the river. Most notably were the vast numbers of alewives and striped bass. Wood wrote that fish weirs on the river were able to take "ten thousand (alewives)…in two hours…" and that the Indians and English would use hook and line to catch striped bass, "…some fifty or threescore at a tide". In Rumney Marsh, there was at least one brook, which smelts and frost fish (tomcod) used for spawning. Continuing further towards the sea, Wood reported that mackerel were so plentiful that "…Bass have driven up shoals of Mackerel from one end of the sandy beach to the other…". He also mentioned that this area contained"…a great deal of Rock-cod".

In addition to obtaining information from Janet Regan of the NPS, historical "Wakefield Fish Committee Reports", which were provided in the Wakefield Annual Town Report, were obtained from the Wakefield Public Library. These annual reports dating back to the late 1800's and early 1900's describe fish species in Lake Quannapowitt, and the migration of alewives to Lake Quannapowitt. Fish Committee Reports for the following years were reviewed: 1877, 1880, 1885, 1887, 1888, 1890, 1895, 1900, 1903, and 1910. It should be noted that after about 1910, there was no mention of the Fish Committee reports in the Wakefield Annual Town Reports.

The reports note that with the construction of numerous mills and dams, migrating fish, such as alewives could not ascend the Saugus River during their spring migration period. The reports state that during the late 1800's State Fish Commissioners required mill-owners to install fishways to allow migrating fish to reach spawning habitats. With the installation of fishways, alewives returned to Lake Quannapowitt and the fishery in the lake, according to the Fish Committee reports, thrived during this time period. A passage from the 1887 Committee report follows: "The run of Alewives to Lake Quannapowitt during the past season has fully sustained our expectations, as expressed in our previous annual reports, being larger than ever before". The 1887 report also provides information on the species, number and weight of fish caught from Lake Quannapowitt as follows:

“That the fishing is improving, year by year, in a rapidly increasing proportion, a glance at the statistics given below.”

Consolidated Returns for 1886

Number of Permits Issued	293
Number of Permits returned, (including 13 not used)	60

These 47 (used) returns show results as follows:

Number of Black Bass,	132
Number of Pickerel,	742
Number of White Perch,	173
Number of Red Perch,	2,739
Miscellaneous Fish,	690
Total No. of Fish,	4,467
Total Weight	1,811 lbs

“Your Committee have the best of reasons for the belief that complete and correct returns from all holders of permits would show more than 9,000 lbs of edible fish taken from Lake Quannapowitt during the last season’s fishing”.

Based on a review of the reports, the following species were noted: shad, salmon (stocked), alewives, bass, pickerel, white perch, red perch, shiners (stocked), black bass, German carp (stocked), redfin perch, eels, ministers, rainbow trout (stocked), and pike-perch. It was unclear from the reports whether these fish were only seen in Lake Quannapowitt or along the Saugus River mainstem. Since the reports focused on Lake Quannapowitt it is suspected that the species list is based on fish captured in the lake.

Janet Regan also provided other historical accounts. Benjamin Newhall writes in the 1850s that:

> In former years the fishing business was carried on upon the river to considerable extent. Now, it is almost wholly neglected. Bass, shad, alewives, perch, smelts, and eels were among the fish taken, some of them in large quantities. Now they seem generally forsaken, except the eels, which are taken in large amounts in the winter. In 1810 to 1814 the alewife fishery was carried on very extensively, furnishing several hundred barrels yearly, which found a ready sale for the West India trade. The fish were taken by seines at two points in the river, one just below the mills, and the other on the “Cinder Banks” so called, at the head of the tide water. Sometimes they were so plenty that large quantities were taken in scoop nets.

Long after fishing had ceased to function as a means of survival, the activity lingered as a favorite pastime. Originally the fish were naturally plentiful, but after the various dammings and the problems of industrial waste it narrowed down the fish population. The river was stocked for the sake of restoring its natural balance as well as providing recreational fishing for the various communities. It still is periodically stocked, both by private organizations and state agencies, however, the fish have great difficulty spawning in their traditional grounds. Smelts, for example, a traditionally plentiful fish in the Saugus River, are disappearing because the cobble upon which they lay their eggs is now covered with a thick coating of slimy algae, the product of excessive nutrients.

9.2 Current Fish Species Present in Saugus River Watershed

The database of fish species present in the Saugus River was obtained from the Hudsonia Report, historical records and visual observations. Much of the information contained in the Hudsonia report is summarized below.

Hudsonia Study

Fish sampling in the freshwater portion of the Saugus River was conducted in 1989 as part of the Hudsonia study. Hudsonia conducted fish sampling using electroshocking or seines at five locations in the Saugus River. Sampling was conducted on May 25, August 9 and October 10, 1989 to identify the presence and abundance of fish in the river. Stunned or netted fish were identified to species level in the field and released.

Nine species of fishes in seven families were collected during the study as shown in Table 9.2-1.

Table 9.2-1: Fish Sampling Locations and Number of Fish collected (Hudsonia)

Station	Sampling Location	Sampling Dates and Species (No. of Species) Collected			
		Species	May 25	Aug 9	Oct 10
1	Confluence of Saugus and Mill Creek	Redfin Pickerel	2	2	0
		Chain Pickerel	1	0	0
		Bluegill	1	0	0
		White Sucker	2	0	0
		American Eel	0	4	3
2	at Route 1 Bridge	American Eel	1	1	3
		Yellow Perch	0	0	3
3	Lynn Fels Parkway	American Eel	3	1	2
		Banded Sunfish	2	0	0
		Redfin Pickerel	0	1	0
		Yellow Perch	0	1	0
4	Downtown Saugus	American Eel	5	7	4
		Mummichog	8	8	ca. 100
5	Saugus Ironworks	American Eel	19	11	7
		Fourspine Stickleback	2	1	2
		White Sucker	0	5	8
		Mummichog	0	0	36

Coastal streams in Massachusetts do not typically have a diverse fish fauna partially because of the biogeographic history of the area and partially because these streams are low gradient, sandy and stained with tannins. Many fish species, common in the rest of the state, will not tolerate coastal plane conditions.

Hudsonia expected fish diversity in the Saugus River to be low, but the fish fauna were more depauperate than expected. Two of the species Hudsonia collected, mummichog and fourspine stickleback are euryhaline[19] marsh species that often penetrate into the mouths of freshwater streams, but are not considered true freshwater species. These species were collected at Stations 4 and 5, near the salt water.

The most common and widespread species in the Saugus River is the American eel, a catadromous[20] fish found in virtually all coastal waters in New England. The species has a very high tolerance for poor water quality. Three of the remaining species were game species, probably introduced by humans. They are chain pickerel, yellow perch, and bluegill.

Hudsonia collected only three species that are a part of the native freshwater coastal plain fish fauna: redfin pickerel, white sucker, and banded sunfish. Other species, which Hudsonia considered to be more typical of coastal plain streams, were absent: golden shiner, creek chubsucker and swamp darter.

Hudsonia reported that a second indication of poor water quality, in addition to the short species list, was the number of individuals collected. Each sample consisted of shocking 100 feet of stream and counting all individuals seen and/or caught. The number of individuals caught at Station 1 was between three and six individuals per 100 feet. Station 2, 1-5 individuals; Station 3, 2-5, Station 4, 13-104 and Station 5, 19-53. Hudsonia noted that the last two stations have numbers that they considered reasonable (at least in the larger collections), but these were primarily eels and mummichogs, not typical stream fishes. Ignoring the tolerant eels and the euryhaline species, the number of individuals collected is extremely low and indicative of poor water quality.

Visual Observations

In addition to Hudsonia's study, during the habitat mapping and other field visits by Gomez and Sullivan other species were identified namely carp and bass. Carp were seen at the base of the Diversion Dam and are most likely "drop-downs" from Reedy Meadows when the dam sluice gate is opened. Also, bass (not sure if they were small or large mouth) were identified in the canal, when the canal sluice gate was opened. Again, these were drop-downs from Reedy Meadows. During the habitat mapping, 5-6 largemouth bass were also seen at the Camp Nihan Pond.

Also during the spring 2000 and 2001, LWSC officials reported alewife present near the Diversion Dam.

[19] Euryhaline- able to live in waters of a wide range of salinity.
[20] Catadromous- living in fresh water and going to the ocean to spawn

Massachusetts Division of Fisheries, Wildlife and Environmental Law Enforcement (MDFWELE)

The MDFWELE was also contacted to determine if any historical stocking or creel surveys had been completed. Peter Jackson provided two MDFWELE memos regarding the Saugus River. The first memo, dated October 20, 1977, discussed the past, present and future fishery management policies on the Saugus River from Water Street south to below Pranker's Pond (south of Route 1). The memo reports that this stretch of the Saugus River had previously been stocked with varying numbers of brook trout until 1969. Trout stocking was terminated in 1969 primarily due to low-flow conditions.

The memo summarizes that the Saugus River is predominantly a warm-water, highly fertile (high nutrient levels) stream characterized by high summer water temperatures, low dissolved oxygen concentrations and unstable flow conditions, all of which preclude its stocking with trout in the future.

The second memo, dated November 2, 1995, discusses the Saugus River stocking history, which is summarized below.

April 1983- 450, 6-7", Brook Trout
April 1984- 700, 6-7", Brook Trout
April 1985- 800, 6-7", Brook Trout
May 1986- 300, 6-9", Brook Trout
May 1987- not stocked
1988- 500, 6-9", Brook Trout (month not provided)

The memo indicates that the Malden Chapter of Trout Unlimited contacted the Massachusetts Division of Fish and Wildlife (now MDFWELE) in 1983 concerning stocking a small number of trout into the Saugus River. Trout Unlimited had done an extensive amount of assessment work on the river, which MDFWELE reviewed and found suitable for stocking trout. No further stocking was conducted since 1988.

It is interesting to note that stocking continued up to 1988, a year before the Hudsonia creel survey. However, no brook trout were identified in Hudsonia's 1989 survey.

Massachusetts Department of Environmental Protection

Fish sampling of Lake Quannapowitt was also conducted as part of the MDEP's Water Quality Study on May 18, 1998. Sampling resulted in the collection of largemouth bass, yellow perch, white perch, common carp, brown bullhead, and black crappie.

9.3 Ipswich River Fish Assemblage

The Ipswich River watershed lies just north of and is adjacent to the Saugus River Basin. It flows in a general eastwardly direction and empties into the Gulf of Maine at the town of Ipswich. Average monthly discharge ranges from 37.2 cfs in September to 449 cfs in March.

Alterations and changes in the water use (similar to those of the Saugus River) of the Ipswich River have dramatically reduced its flow during low-flow periods. The Ipswich River was evaluated since there was limited data available on the Saugus River and it expected that the present and historical fish species on the rivers would be similar.

Fish Species of the Ipswich River

The Ipswich River Fisheries Restoration Task Group (composed of representatives of the Ipswich River Watershed Association, Essex County Greenbelt Association, Massachusetts Audubon Society, MDEP, Massachusetts Division of Marine Fisheries, MDFWELE USGS, U.S. Environmental Protection Agency and U.S. Fish and Wildlife Service) produced a document (Ipswich River Fisheries Restoration Task Group, Draft Report, June 11, 2001) detailing the target Fish Community for the river based on the premise that the native species would be those present in the absence of human alteration of the hydrology and physical nature of the river. Using historical and recent data collected from the Ipswich and Essex County, MA, more recent data from the Lamprey River, NH (which is similar in watershed area, discharge and geology) and professional judgment, the Task Group identified the current and reconstructed the historical fish assemblage for the Ipswich River.

Historically, 67% (relative abundance) were fluvial or stream species; the five most abundant species were those requiring fluvial habitats and accounted for 60% of the total abundance. The current fish community is markedly different and represented mostly (81.6%) by macrohabitat generalists. Only 8.9% are fluvial species and several fluvial species expected to be present were absent from the river. Shown in Figure 9.3-1 are the current and reconstructed historical fish assemblages (and relative abundance) for the Ipswich River. In addition to species shown in Figure 9.3-1, other diadromous[21] species were noted as part of the historical fish assemblage. Species identified included: alewife, blueback herring, American shad, smelt, sea lamprey, American eel, Salter brook trout, and salter brown trout.

[21] This term is used to denote those species that migrate into or out of freshwater in a concentrated manner, e.g. a fish run.

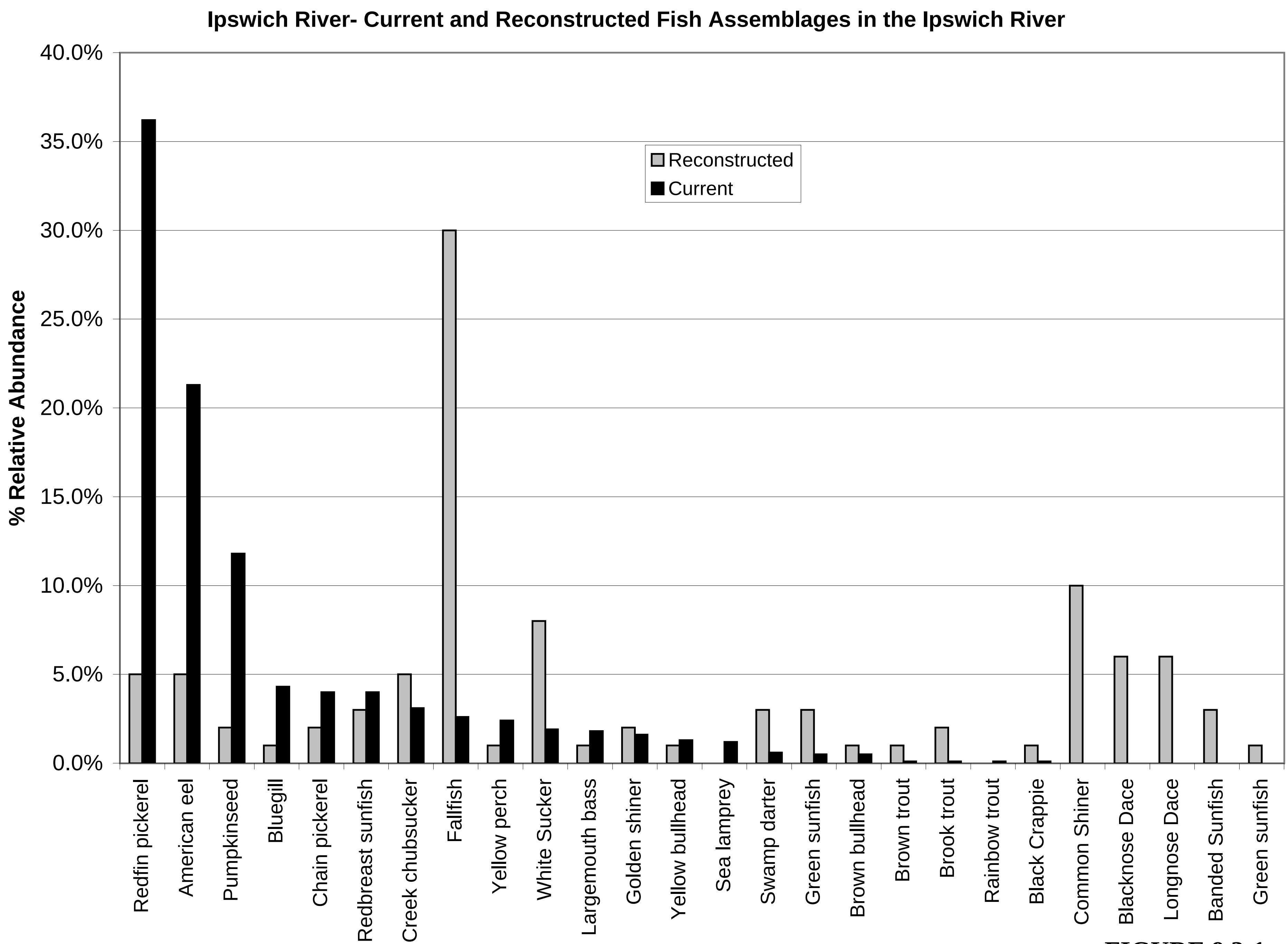

Ipswich River- Current and Reconstructed Fish Assemblages in the Ipswich River
% Relative Abundance
40.0%
35.0%
30.0%
25.0%
20.0%
15.0%
10.0%
5.0%
0.0%
Reconstructed
Current
Redfin pickerel
American eel
Pumpkinseed
Bluegill
Chain pickerel
Redbreast sunfish
Creek chubsucker
Fallfish
Yellow perch
White Sucker
Largemouth bass
Golden shiner
Yellow bullhead
Sea lamprey
Swamp darter
Green sunfish
Brown bullhead
Brown trout
Brook trout
Rainbow trout
Black Crappie
Common Shiner
Blacknose Dace
Longnose Dace
Banded Sunfish
Green sunfish

FIGURE 9.3-1

10.0 Target Species, Habitat Suitability Index Curves, Substrate Coding System

10.1 Target Species

Using the historical and current fish data on the Saugus River (and the nearby Ipswich River), and after consulting with the MDFWELE a target species listed was developed for the Saugus River instream flow study. The goal of this exercise was to identify species likely to inhabit the river under a natural flow regime. MDFWELE wanted to ensure that the species list represented riverine fish versus pond fish (such as yellow perch). It should be noted that the species list is limited to some extent by the availability of habitat suitability index curves (HSI)- see discussion below on HSI curves. In some instances HSI curves for a given species were unavailable and therefore no assessment could be conducted. Given this, the following list of species was identified:

- All life stages of White Sucker,
- All life stages of Fallfish,
- All life stages of Common Shiner,
- All life stages of Alewife (no HSI curves exist, but alewife were evaluated qualitatively),
- All life stages of Longnose Dace and,
- Macroinvertebrates.

Based on historical water temperature measurements in the Saugus River (as described earlier), the river falls within the Class BWWF (Class B warmwater fishery). The upper watershed has many expansive areas of shallow water (Lake Quannapowitt, Reedy Meadows) that result in heating the water delivered to the watershed below the LWSC Diversion Dam. In summary, the species list matches the warmwater characteristics of the Saugus River.

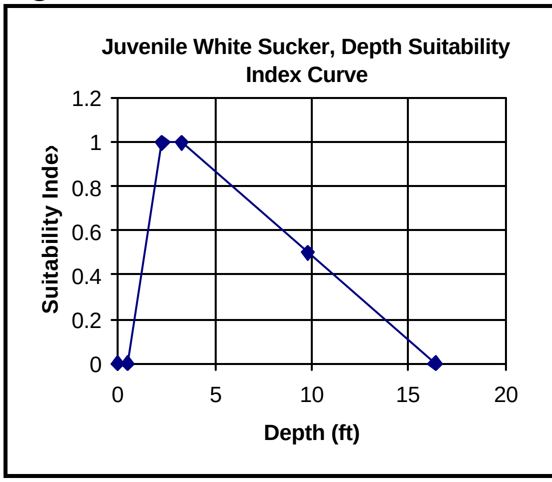
10.2 Habitat Suitability Index (HSI) Curves

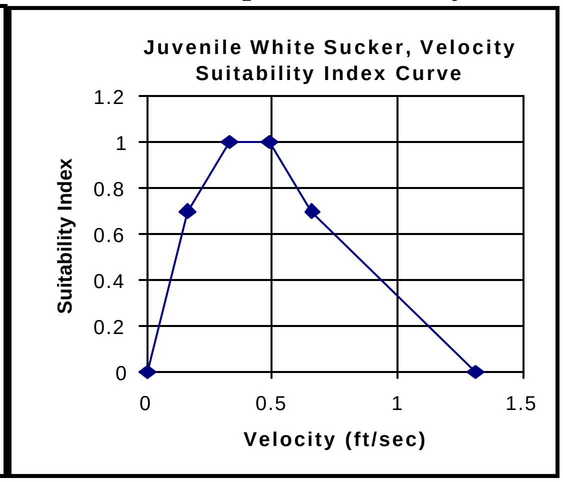
Each life stage and species of fish has preferences for macrohabitat needs (DO, temperature, food supply) and microhabitat needs (depth, velocity, substrate). Studies have been conducted on some species (and life stages) to identify both macro and microhabitat needs. The studies consisted of taking field measurements where fish are observed in water and noting the depth, velocity, substrate, DO, temperature, etc at the fish's location. Several of these studies were conducted, most in the western U.S., and the results were combined to generate habitat suitability index (HSI or SI) curves. The United States Fish and Wildlife Service (USFWS)[22] has habitat suitability index information for some fish species, which include information on the age, growth, water quality and food requirements. In addition, the USFWS reports contain habitat suitability index curves, which describe fish preferences for depth, velocity, substrate, temperature, dissolved oxygen and cover (it was beyond the scope of this study to examine temperature, and dissolved oxygen habitat). For example, shown in Figure 10.2-1 are habitat suitability index curves (depth, velocity) for juvenile white suckers (substrate curve is not

[22] The list of available habitat suitability index data for fish and wildlife are provided by the government on the following web site: http://www.mesc.usgs.gov/hsi/HSI_models_available.html.

shown). It should be noted that HSI data is available primarily for microhabitat needs (depth, velocity and substrate).

Figure 10.2-1: White Sucker, Juvenile, HSI Curves for Depth and Velocity





Suitability index curves describe the preference for fish using a scale from 0 to 1. A suitability index value of 0 indicates no habitat value, while a suitability index value of 1 indicates optimal habitat value. For example, keying off the juvenile white sucker curve above, the optimal depth and velocity for this particular species is 2.3 to 3.3 feet, and 0.33 to 0.49 ft/sec, respectively.

The USFWS habitat suitability index curves were compared to the five species identified above for this study. Shown in Table 10.2-1 are the sources used in developing the HSI curves.

Table 10.2-1: Sources for Habitat Suitability Index Curves

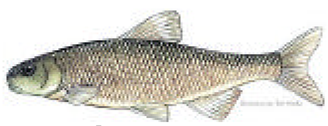
Species	Life Stage	Source
Common Shiner	Spawning and Incubation Fry Juvenile Adult	Moody R.C. Habitat use, availability and preference for johnny darter, white sucker, common shiner and creek chub in central Wisconsin (1989) USFWS Habitat Suitability Information and Instream Flow Suitability Index Curves (1983)
Fallfish	Spawning and Incubation Adult Fry Juvenile	Developed in Consultation with the New York Department of Environmental Conservation Velocity and depth based on Brook Trout Fry and Juvenile HSI curve (Developed as part of a Delphi Process for the Deerfield River in VT and MA)
White Sucker	Spawning and Incubation Fry Juvenile Adult	USFWS Habitat Suitability Information and Instream Flow Suitability Index Curves (1984)
Longnose Dace	Spawning and Incubation Fry Juvenile Adult	Library of Midcontinent Ecological Science Center, US Geological Survey, and modified by the Vermont Department of Fish and Wildlife.
Alewife		No Habitat Suitability Index Curve data is available
Macroinvertebrate	All life stages	Jirka, Kurt J. and Homa, John, Habitat Suitability Index

Species	Life Stage	Source
		Curves for Selected Taxa on Benthic Macroinvertebrates (1989)

As noted in Table 10.2-1 some HSI curves were based on revisions to the USFWS HSI curves or were obtained from other sources. For example, fallfish HSI curves are not readily available, however, Gomez and Sullivan has worked closely with fish biologists with the Vermont Department of Fish and Wildlife on Vermont streams to develop HSI curves (instream flow studies, similar to the Saugus study, were conducted on Vermont streams). Similarly, Gomez and Sullivan worked with the Vermont Department of Fish and Wildlife to adjust the published USFWS HSI data for longnose dace to be applicable to Vermont Rivers. Also, the macroinvertebrate curve was developed from field-based measurements taken on New York streams. No habitat suitability index data is available for alewife. As such, analysis of this species will be qualitative versus quantitative.

The habitat requirements for each of the target species are summarized below based on habitat suitability studies. Habitat suitability index curves for the species listed below are contained in Appendix I.

Common Shiner



General

The range of the common shiner extends from the Atlantic coast west through southern Great Lakes drainage to the eastern Dakotas. It is widely distributed in streams and lakes along the Atlantic coast, from Novia Scotia south to the James river system in Virginia.

Age, Growth, Food

The common shiner is a short-lived, small minnow. Males grow faster than females and reach a larger size. The adult size ranges from 64 to 102 mm[23]. Common shiners are omnivorous, feeding on nearly equal amounts of plant and animal matter. Water level variation is a major factor explaining feeding variability. Increased turbidity reduces the availability of insect larvae, resulting in an increase in the intake of plant matter. Common shiners feed readily on the bottom, in the water column, and at the surface.

Reproduction

The common shiner is predominantly a stream-spawning fish, but in some inland lakes in Michigan, it may also spawn over gravel shoals. Substrate between 5 and 60 mm is utilized for spawning. Common shiners excavate depression nests in gravel or sand or use nests built by other fish. The eggs are adhesive and lodge among the gravel. Most nests are built in riffles 13 to 44 mm deep. At any one location spawning lasts 10 to 20 days and is limited to the daylight hours. This species spawns from May to July, when water temperatures are 15.5 to 18.3°C.

[23] 1 inch= 25.4 mm, 1 mm=0.03937 inches

Spawning migration in Maine coincided with high water and occurred at temperatures of 12 to 16°C.

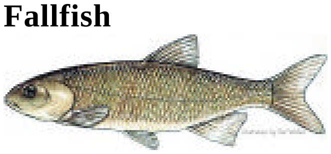
Specific Habitat Requirements

Adult: The adult common shiner typically occurs in small and medium-sized streams with clear, cool water, a moderate current; and an unvegetated gravel or rubble bottom. These minnows frequent pools in streams more often than rapids. They congregate in pools immediately below cascades, but not in deadwater or long pools.

Fry-Juvenile: After emerging, fry leave the nest areas in the riffles and congregate just under the surface in pools, which serve as nursery and juvenile habitat. Small fish, about 15 mm long, school in pools that are typical of moderate gradient streams.

Embryo: Spawning sites are located in depressions in sand or gravel over which the current forms an eddy. This creates conditions in the nest that enhance water circulation, preventing siltation and increasing oxygen availability.

Fallfish



General

Fallfish inhabit rivers, streams and lakes from New Brunswick south along the east coast of the United States to Virginia.

Age, Growth and Food

The fallfish is a long-lived fish, with an age of XI (11+ years old). Adult size usually varies from 155 mm to 255 mm. The sexes grow at similar rates to age IV (4+ years old), after with the growth rate of males exceeds that of females. Fallfish are opportunistic feeders; their diet includes aquatic insect larvae, terrestrial insects, crustaceans, and fish. Algae is also an important constituent of the diet.

Reproduction

Although some fallfish mature at age II (2+)or III (3+), most do not reach maturity until age IV (4+ years old). Spawning typically occurs in the spring after water temperatures reach 15 °C. Spawning activity, once initiated, may cease if water temperatures drop below 15 °C. Fallfish spawn in quiet waters of streams and in the shallow margins of lakes. Observations in Maine indicated that fallfish move from larger waters into streams to spawn. Fallfish usually construct nests in stream reaches where overhead cover, such as overhanging vegetation or dead brush, or pools occur near areas of suitable spawning substrates.

Nests in the Mill River near Amherst, MA were constructed in midstream or at the stream edge at depths of 0.5 m[24] (1.6 ft) or less. Males move gravel and sand upstream with their mouth and deposit it as a mound, which forms a nest.

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[24] 1 foot= 0.3048 meters, 1 meter=3.281 feet

Specific Habitat Requirements
Adult: Adult fallfish prefer clear, gravel-bottomed streams and lakes. Larger adults seek pools and deep runs in their riverine habitats. The probability of finding larger individuals increases as the size of the water body increases. Fallfish are commonly found near cascades and falls. They seldom occur in water over 28 °C.

Embryo: Embryo incubation usually occurs at temperatures between 16°C and 18°C. Eggs hatch in 138 to 144 hours at 17°C.

Juvenile: Juvenile fallfish frequent rapid water more than adults. Observations in Maine suggest that juveniles occur in smaller streams than adults.

White Sucker

General
The white sucker is a highly adaptable, freshwater fish species found in lacustrine and riverine environments throughout various waterways of the United States and Canada.

Age, Growth and Food
Male white suckers typically reach maturity between ages II and VI (2+ and 6+ year old), depending on geographic location. Females usually mature 1 to 2 years later than males. Sac-fry feed on surface associated zooplankton or on suspended phytoplankton. After yolk absorption, they shift to bottom feeding. Juveniles feed primarily on benthic organisms. As size increases with maturation, the size of the food items ingested increases. White suckers are active and feed throughout the year. Maximum growth occurs from June to August.

Reproduction
White suckers start their upstream spawning migration in spring to early summer, when the daily maximum water temperature reaches 10°C. The migration continues until the water temperature reaches about 18°C. Initiation of spawning migrations appears to be either temperature-dependent and/or stream discharge-dependent. Sudden temperature drops may diminish or stop migration. White suckers usually migrate from lentic (still waters such as pools, ponds or swamps) systems or stream pools to spawning riffles; therefore it is assumed that distance to spawning habitat may be a factor in determining optimum habitat.

White sucker spawning habitat is generally considered to be areas in inlets, outlets, small creeks and rivers with relatively swift shallow water runoff over a gravel bottom. One study reported that spawning over gravel was usually at water depths less than one foot. A clean bottom of coarse sand or gravel is an essential quality of the spawning habitat for white suckers.

Specific Habitat Requirements

Adult: White suckers have broad temperature tolerances, and optimum temperatures vary geographically. The literature reports a range of suitable temperatures ranging from 19-24°C, while maximum lethal temperatures are approximately 31.6°C. Specific minimum temperatures have not been reported, but the wide distribution of white suckers indicates that they can survive temperatures as low as 1-2°C.

Embryo: Embryo development is temperature dependent with reports indicating that eggs were located in temperatures between 11-16°C. Hatching success diminishes significantly at temperatures <9°C or >17°C, and the upper and lower lethal limits were 24 and 6°C, respectively.

Larval: White sucker larvas apparently prefer water temperatures of 23-25°C, but occur in water temperatures in 13-25°C. One study reported that young suckers were found in streams where the substrate was a mixture of sand and gravel. White sucker fry prefer moderate currents and do not occur in rapids or still pools, although they may be present in intermediate situations where the stream enters deep, quiet stretches. Young suckers in the surface-feeding stage appear to congregate in eddies and backwaters in response to gentle currents.

Juvenile: Upper lethal temperature limits for juvenile white suckers were 26-31°C with approximate lower limits of 2-6°C. Small white suckers have been collected from shallow backwaters, riffles with moderate water velocity and sand-rubble bottom runs.

Longnose Dace

General
The longnose dace occurs from coast to coast across North America as far south as the Rocky Mountains in Mexico and as far north as the McKenzie River near the Artic Circle. The species is more widespread on the Atlantic slope, where it extends south through the Appalachians to Georgia, than in the west, where it extends along the Rocky Mountains and throughout the Pacific slope from Oregon north.

Age, Growth and Food
Longnose dace mature at age II (2+ years). The oldest reported individual of this species was V years old. Adults are usually above 6.3 to 8.8 cm in length. Longnose dace are well adapted for feeding on the bottom and will eat whatever is abundant. Riverine populations feed mainly on worms, mayflies and black flies, although they will feed on other aquatic insects. Fry eat algae and, as they grow, will eat mayflies and worms. Juveniles eat mainly mayflies and worms.

Reproduction
Longnose dace select and defend territories during the breeding season. The peak of longnose dace spawning usually occurs in June to early July in both lakes and streams. Spawning may occur as early as May and as late as August, depending on water temperature. Spawning occurs

when the daily maximum temperature exceeds 15°C. In Lake Michigan, longnose dace began to come into shore at 8 to 14°C and peak spawning occurred at 14 to 19°C.

In streams, longnose dace spawn only in riffles with a velocity of 45 to 60 cm/sec[25]. Spawning is restricted to places where the substrate is coarse enough to provide natural depressions in the substrate for egg deposition. The substrate in streams is usually gravel and rock with an upper limit of 5 to 20 cm in diameter. Overhead cover and shelter from current is always present.

Specific Habitat Requirements

Longnose dace are most abundant in swift flowing, steep gradient, headwater streams of larger river systems. The stream habitat is usually boulder-strewn, with gravel and rock beds, and may be classified as a "trout stream". Longnose dace probably live in streams with gradients of 1.9 to 18.7 m/km.

All age groups of longnose dace occur in very shallow water, usually less than 0.3 m deep and rarely greater than 1 m deep. Overhead cover and shelter from current is required during all seasons. Longnose dace are usually collected in streams with a current velocity greater than 45 cm/sec.

Specific turbidity tolerance limits are unknown, but the species tolerates waters that are temporarily turbid, murky or muddy.

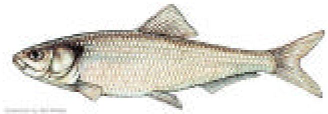
Adults: Adult longnose dace prefer riffle areas in streams but will occupy quiet, shallow water pools in the absence of competing species, especially during the summer. Adults usually live in the protection of crannies between stones and very fast water. They are most abundant in waters with a current velocity greater than 45 cm/sec.

Embryo: The eggs of longnose dace are adhesive and are deposited in natural depressions. Optimum spawning temperatures range from 14 to 19°C. Incubation takes from 7 to 10 days at 15.6°C. The yolk sac is absorbed in about 7 days after hatching.

Fry: In both lakes and streams, fry are abundant in the protected margins of quiet shallow water. Fry show a preference for areas with overhead cover. In general, juvenile habitat requirements are similar to those for adults.

Juveniles: In streams, juvenile longnose dace are in riffle areas with velocities greater than 45 cm/sec, but will seek out quieter areas.

Alewife



General

The alewife is an anadromous species utilizing freshwater rivers to spawn and grow during their first few months after hatching.

Age, Growth and Food

Eggs drift in the water column within 24 hours of fertilization and hatch within 2-5 days. The fry remain in shallow (<2 m) water. Juveniles (>25mm) remain in freshwater and emigrate to estuaries and coastal areas generally in the fall and early winter when they are >30mm long. Emigration can begin as early as June in lower latitude populations. Upon return to freshwater to spawn, alewives are about 240mm (3+ years old) to 350mm (8+ years old). All life stages eat planktonic organisms and participate in three feeding strategies: particulate feeding of individual organisms, filter feeding, and gulping of several prey organisms at once.

Reproduction

Spawning takes place from late March through July and is initiated at 10.5°C. Although a small proportion of age III (3+ years) fish spawn, most of the spawners are age IV (4+ years) and older. Males typically enter rivers before females. Alewives tend to spawn in slow-moving water but will also spawn in fast currents. Adults migrate downstream within a few days after spawning.

Specific Habitat Requirements

Adults: Spawning runs for river herring begin in spring and minimum spawning temperatures are 10.5°C and 14°C for alewives and blueback herring, respectively. Both species cease spawning when water temperatures exceed 27°C.

Egg: Hatching times for fertilized alewife eggs vary with water temperatures. Typically, hatching requires 80-95 hours for alewives. Hatching success of alewives is directly correlated with water temperatures. Hatching was maximally successful at 20.8°C, fell significantly at 26.7-26.8°C, and did not occur at 29.7°C.

Larva: Daily weight gains in young alewives were greatest at 26.4°C and their temperature preference was estimated at 26.3°C in thermal gradients. In Nova Scotia rivers, larvae are associated with relatively shallow (less than 6.6 feet), sandy, warm areas in and near areas of observed spawning.

Juvenile: Juvenile river herring migration from freshwater-estuarine nursery areas at age 0+ is in response to heavy rainfall, high water, and water temperature declines. During the winter they have been found in lower portions of estuaries out to five miles offshore.

Shown in Table 10.2-2 is a periodicity chart, which summarizes when certain life stages would be expected to be present in the Saugus River on a monthly basis. This information is helpful when determining a flow recommendation, as the flow needs for various life stages varies throughout the year.

Table 10.2-2: Periodicity Chart - Timing of when Species/Life Stages are expected to be Present in the Saugus River

Species	Life Stage	Month											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Alewives	Upmigration												
	S&I												
	Fry												
	Juvenile												
	Emigration												
	Adult	Adults migrate upstream to spawn and then return to the sea											
Fallfish	S&I												
	Fry												
	Juvenile												
	Adult												
Common Shiner	S&I												
	Fry												
	Juvenile												
	Adult												
White Sucker	S&I												
	Fry												
	Juvenile												
	Adult												
Longnose Dace	S&I												
	Fry												
	Juvenile												
	Adult												

10.3 Substrate Coding

As noted above, suitability criteria for each of the target species/life stages are based on habitat variables of depth, velocity and substrate. Substrate, similar to velocity and depth, plays a vital role in fish habitat- particularly as it relates to spawning. While velocity and depth were measured directly with flow metering equipment, substrate was identified by eye using a coding system as shown in Table 10.3-1. Substrate codes were characterized based on substrate size, percent embeddedness and cover.

Substrate refers to the material armoring the channel such as sand, gravel, boulder, etc. Substrate is an important variable as certain species and life stages of fish prefer different substrate types. For example, adult fallfish will seek fast moving water with gravel substrates for spawning. Cover was also recorded as either providing few or abundant velocity refuges. Velocity refuges such as large or small boulders allow fish to seek refuge from high water velocities. In general, cover is limited in the Saugus River as most substrates are smaller than 10 inches in diameter. Percent embeddedness was also recorded, which refers to the amount of fine material in interstitial spaces between the dominant substrate. As noted above, fallfish adult prefer to spawn in gravel substrates. If gravel is highly embeddeded with silt material, the quality of spawning habitat is not as ideal than if the gravel was "clean" with little fine material. As a general note clean gravel substrates are very limited in the Saugus River. In fact, most of the river is confined to softer silt, sand or muck substrates.

Table 10.3-1: Substrate Coding System

Substrate Code	Embeddedness Code	Cover Code
1- Roots, Snags, Undercut Banks 2- Clay 3- Silt 4- Sand 5- Small Gravel (<2") 6- Gravel (2"-4") 7- Cobble (4"-10") 8- Boulder (10"-2') 9- Boulder (>2') 10- Ledge 11- Detritus, vegetation	.2- Embeddedness (0-25%) .5- Embeddedness (26-50%) .7- Embeddedness (51-75%) .9- Embeddedness (76-100%) Note: Embeddedness refers to the amount of fine material (such as sand) in interstitial spaces.	.03- Few Velocity Refuges .06-Abundant Velocity Refuges
Example Field Code: 5.53= Small Gravel (5), 26-50% Embedded (.5) with few Velocity Refuges (.03)		

11.0 IFIM Field Data Collection

11.1 Summary of Field Data Collection

The instream flow field crew mobilized four times to collect depth, velocity and substrate information in the two reaches described earlier. The dates of data collection are listed in Table 11.1-1.

Table 11.1-1: Dates of Field Data Collection

Reach	Dates of Data Collection
Diversion Dam Reach	June 4, 5, 6, 2001
Staples Reach	June 4, 5, 2001 and July 31, 2001

Prior to mobilizing the field crew on June 4, 2001, it was requested that LWSC open the Diversion Dam gate to release approximately 5 cfs 12 hours in advance of the field crew's arrival. By maintaining the desired flow 12 hours earlier, it was assumed that flow conditions would stabilize in the lower reaches on the afternoon of June 4 (when data would be collected in the Staples Reach). Although the target flow was 5 cfs, the average flow measured at the Diversion Dam was approximately 0.43 cfs. After discussing the large discrepancy between the measured and target flow with LWSC, it was noted that the Diversion Dam gate had become clogged with debris, which restricted flow.

On the afternoon of June 4 the field crew mobilized to the Staples Reach. Flow measurements at the four transects varied and it was suspected that flow conditions were not stable. Temporary staff gages were placed at each transect and slight differences in the staff gage readings were noted just before, and after a transect was metered. It should be noted that the hydraulic model used to simulate velocity and depth conditions is based on steady-state (flow cannot vary) conditions, however, flows measured at the four transects varied (unsteady flow). Because flow was unsteady, the USGS and MDEM were contacted to obtain flow and precipitation data, respectively. The USGS gage on the Saugus River is located at the Ironworks, which is only a few miles below the Staples Reach. Hourly flow data was obtained from the USGS, which is considered provisional at this time. The MDEM also provided daily precipitation data. Shown in Figure 11.1-1 is the hourly flow data at the USGS gage as well as the daily precipitation totals. As the figure shows, flows varied on June 4 in the Staples Reach because of runoff occurring from the June 2 storm event (1.1 inches). Although the release at the Diversion Dam was only 0.43 cfs, runoff from the intervening drainage between the Diversion Dam and Staples Reach was high. Because the measured flows at the four transects in the Staples Reach varied considerably, the data was unusable.

On June 5, the field crew mobilized again. This time the debris that had previously clogged the gate was removed. As before, the gate opening was set around 6:00 pm on June 4 so flows in the Staples Reach (which would be measured on the afternoon of June 5-roughly 20 hours later) would stabilize. The average flows measured just below the Diversion Dam and in the Staples Reach on June 5 were 27.9 cfs, and 24.1 cfs, respectively. The lower flow measurement in the Staples Reach suggests that it takes more than 20 hours for flows to stabilize in the Staples Reach. Flow measurements at the various transects in the Staples Reach on June 5 were more consistent (although the hydrograph on Figure 11.1-1 also varied) and thus the data was considered usable.

On June 6, the field crew collected data only below the Diversion Dam- it was assumed that flows in the Staples Reach would not vary from June 5, and thus data collection here was considered duplicative. The average measured flow was 8.2 cfs.

In an effort to collect a low flow data set in the Staples Reach, the field crew remobilized on July 31, 2001. Flow conditions in the Staples Reach were low- only 3.65 cfs was measured. Similar to the June 4-6 data, shown in Figure 11.1-2 is the USGS hourly flow data for the Saugus Ironworks gage (again, the data is provisional). Flow conditions during the time of data collection were stable and no precipitation had occurred 4 days prior to the field visit.

It should be noted that the measured flows (8.2 cfs and 28.0 cfs at the Diversion Dam and 24.1 cfs and 3.65 cfs) were selected such that habitat conditions could be simulated over a wide range of flows. Section 12 describes how the target flows were used to simulate habitat conditions at flows below, between and above these target flows.

11.2 Data Collection Methods and Procedures

Before flow metering was conducted, pre-marked (at 2 foot intervals) ropes were strung along each transect and were "tied-off" at fixed locations (typically to trees). In many instances eyelets were screwed into the base of trees to secure the ropes. Two flow-metering crews[26] collected velocity, depth, substrate, cover and percent embeddedness data at each cell along each transect. Depth and velocity were measured with flow metering equipment, while visual observation was used to characterize substrate, cover and percent embeddedness. All measurements (depth, velocity and substrate code) were made every 0.5-1.0 foot (called cells) across each of transect.

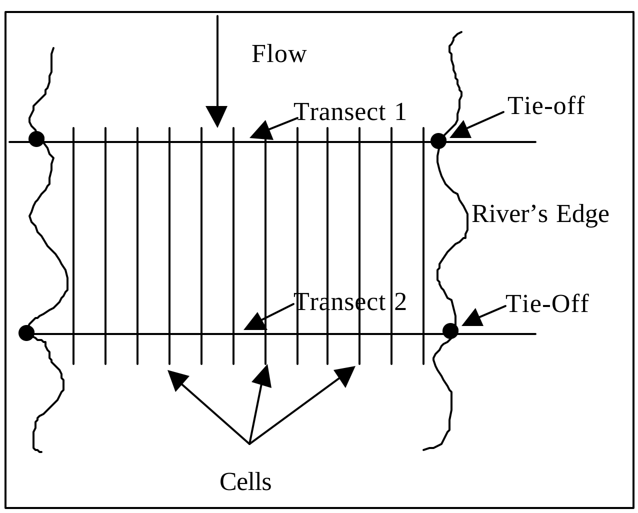


Figure 11.2-1: Example Plan View of Transects showing Cell Locations

[26] A flow metering crew consisted of one person taking notes and the other person collecting field data (depth, velocity, substrate, etc).

For illustration purposes, shown in Figure 11.2-1 is a plan view of a river with two transects. Cells are defined as those areas where depth and velocity measurements were taken (every 0.5-1.0 foot). Cellular velocity measurements were taken along each transect to represent mean velocity conditions in the water column. In keeping with the standard practice for velocity measurements established by the USGS, measurements were taken at a point 0.6 times the depth as measured down from the water surface for water depths less than 2.0 feet. Thus, if the water depth was 1.0 feet, the flow meter would be placed at a depth of 0.6 feet from the water surface. For water depths in excess of 2.0 feet, velocity measurements were taken at 0.2 and 0.8 times the depth and averaged to yield an average column velocity (again this was conducted in accordance with established USGS flow metering practices).

Vertical axis flow meters of the type used by the USGS (see Figure 11.2-2) were used for some velocity measurements. An electronic meter (Marsh-McBirney Flo-Mate) was also used to record velocity measurements. The electronic meter was necessary to measure flow in areas where minimum water depths were not conducive to use of a current meter.

Substrate, cover and percent embeddedness were also collected in each cell using the substrate coding system described earlier.

All flow measurements taken during the survey were keypunched into Excel spreadsheets as shown in Appendix J. In addition, photo documentation of the transects are shown in Appendix K.

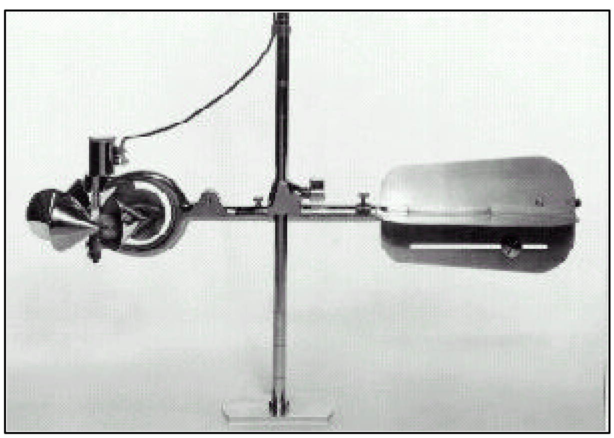


Figure 11.2-2: Illustration of Vertical Axis Flow Meter

11.3 Survey Crew

A survey crew was also mobilized along with the “flow metering” crews. The survey crew was responsible for:

- establishing a temporary benchmark at each reach. The temporary benchmarks were referenced to an assumed datum of 100.0 feet at the Diversion Dam and 200.0 feet at the

Staples Reach. The benchmark locations are shown on plan maps (see Figure 12.2-1 and 12.3-1 in the next section).

- obtaining water surface elevations at each transect within each reach (a water surface profile of the reach was taken),
- ensuring that all transects within a reach were “tied” together or were relative to each other in terms of horizontal and vertical control,
- obtaining survey shots from the transect tie-off points and further up the river banks (as noted later these survey shots were needed when simulating flows greater than the highest field measured flow),
- collecting cross-section data at hydraulic controls.

By implementing the methods and procedures described herein, the transect locations and benchmark locations could be relocated relatively quickly.

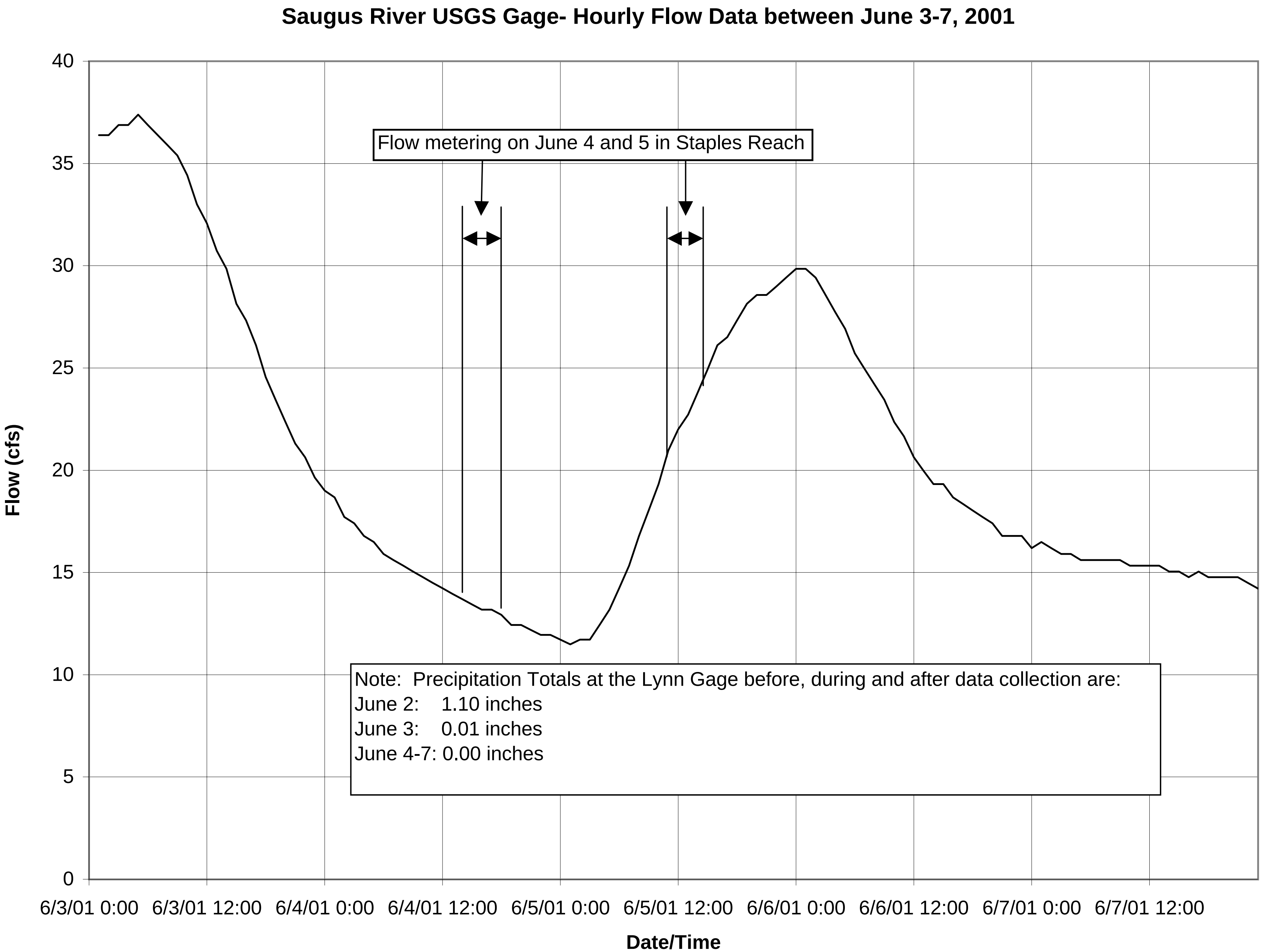
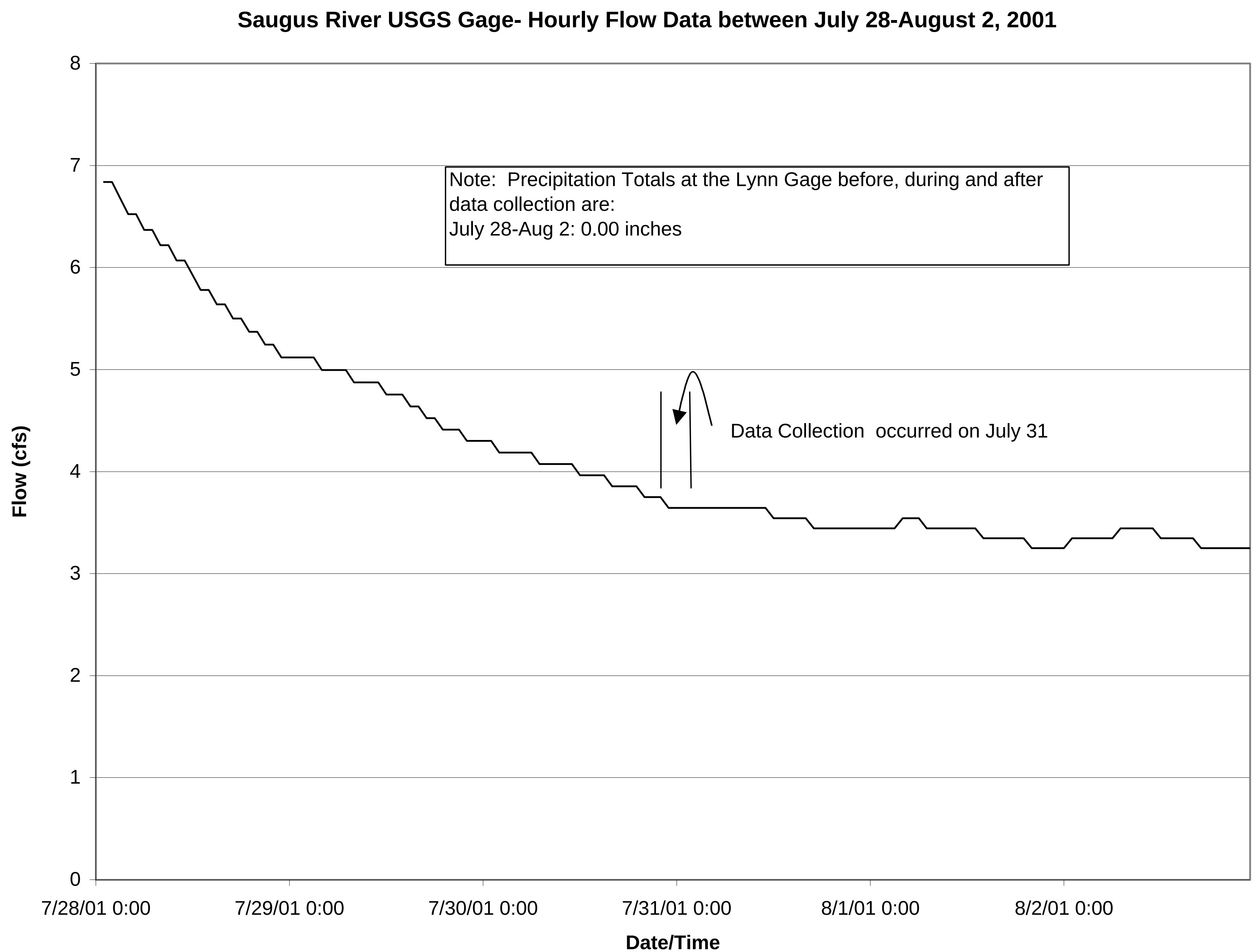

Saugus River USGS Gage- Hourly Flow Data between June 3-7, 2001
Flow (cfs)
40
35
30
25
20
15
10
5
0
Flow metering on June 4 and 5 in Staples Reach
Note: Precipitation Totals at the Lynn Gage before, during and after data collection are:
June 2: 1.10 inches
June 3: 0.01 inches
June 4-7: 0.00 inches
6/3/01 0:00
6/3/01 12:00
6/4/01 0:00
6/4/01 12:00
6/5/01 0:00
6/5/01 12:00
6/6/01 0:00
6/6/01 12:00
6/7/01 0:00
6/7/01 12:00
Date/Time

FIGURE 11.1-1



Saugus River USGS Gage- Hourly Flow Data between July 28-August 2, 2001
Note: Precipitation Totals at the Lynn Gage before, during and after data collection are:
July 28-Aug 2: 0.00 inches
Data Collection occurred on July 31
Flow (cfs)
8
7
6
5
4
3
2
1
0
7/28/01 0:00
7/29/01 0:00
7/30/01 0:00
7/31/01 0:00
8/1/01 0:00
8/2/01 0:00
Date/Time

FIGURE 11.1-2

12.0 Hydraulic Modeling

12.1 Hydraulic Model

A hydraulic model was developed as part of the instream flow study to aid in the habitat analysis. The end result of the habitat analysis is a relationship between flow and aquatic habitat. Only 2-3 sets of calibration flow measurements were made at the Diversion Dam and Staples Reach. Thus the measured relationship between flow and habitat would be limited to only two to three "points". The purpose for developing a hydraulic model is to predict the depth and velocity at each transect for flows other than the 2-3 calibration flows thereby eliminating the need to measure velocity and depth for each flow. In addition, several "points" could be used to describe the relationship between flow and fish habitat.

The Water Surface Profile (WSP) hydraulic model was chosen to simulate hydraulic conditions in both study reaches. WSP is a standard step backwater model that uses the principles of conservation of mass and energy in solving for depth and velocity under various flow conditions[27]. A WSP model is normally calibrated to field measurements for velocity and depth in order to simulate hydraulic conditions in the study reach.

In the hydraulic model, the stream is broken down into a series of rectangular cells, the length and width of which are determined by the distance between transects and transect stationing. After inputting the stream's physical characteristics, the model is calibrated. Calibration is achieved by matching the simulated water surface elevation (WSE) and mean cell velocities to the field measured data. The variable used to calibrate the WSP model is Manning's roughness coefficient "n". Manning's "n" is an empirical coefficient used to: (a) calculate head losses due to friction and (b) distribute flow across the transect. As a general note Mannings "n" is higher for rough bed channels, and lower for smoother bed channels. For example, a Mannings "n" of .03 might represent a smooth natural channel with sand as substrate. Alternatively, a Mannings "n" of .10 might represent a small boulder strewn channel.

The calibration procedure is conducted in two steps. First, the simulated WSE is matched to the observed WSE using a common Manning's "n" for each cell in the transect. Next, the simulated cell velocities are matched with those measured in the field by adjusting Manning's "n" in individual cells across the transect. This trial and error procedure is continued until the predicted WSE and cellular velocities match those measured in the field within a given tolerance. Generally, the tolerance for the predicted stage is +/- 0.10 feet from the measured stage and for the predicted velocities is +/- 0.1 to 0.2 feet/second (fps) of measured velocities.

All cellular velocities at each transect were adjusted so that the flow at each transect equaled the calibration flow. Cellular velocities were adjusted by the following equation:

$V_{target} = (Q_{calibration}/Q_{measured}) \times V_{measured}$, where

V_{target} = Target cell velocities (fps) used to calibrate the WSP data set;
$Q_{calibration}$ = Calibration flow (cfs)

[27] The WSP model is very similar to the commonly known HEC-2 or HECRAS programs.

$Q_{measured}$= Field measured flow for the transect, and
$V_{measured}$= Field measured cell velocity.

The ratio of $Q_{calibration}/Q_{measured}$ is often called the “Velocity Adjustment Factor (VAF)”.

This procedure assumes that all of the error associated with a non-consistent discharge computation is due to velocity measurement. It allows the modeler the ability to proportionately distribute the available flow across a transect without modifying the water surface elevation and carrying inconsistencies over to additional transects.

Due to variations in Manning’s “n” with changes in discharge, there is only a finite range of flows that can be accurately modeled given a single calibration flow. As a general rule, a model is considered valid for flows ranging from 0.4 to 2.5 times the calibration flow.

12.2 Results of Hydraulic Model Calibration for Diversion Dam Reach

The Diversion Dam Reach is located between the LWSC Diversion Dam and the culvert passing under Route 95 (128). This relatively steep 232-foot-long reach consists of fast-moving riffle and run habitat types, with cobble, gravel and sand substrates. Few velocity refuges were available due to the small substrate and fine material was generally highly embedded within the gravel and cobble. Shown in Figure 12.2-1 is a plan map showing the river’s edge, and the eight transects. Table 12.2-1 lists the habitat types where the eight transects were placed. It should be noted that the habitat types were identified during the July 18-21, 2000 habitat mapping exercise.

Table 12.2-1: Transect Location relative to Habitat Types (Diversion Dam Reach)

Transect 1 (upstream most transect - closest to the Diversion Dam)	Run 1 (RN-1)
Transect 2	Riffle-1 (RF-1)
Transect 3	Hydraulic Control
Transect 4	Riffle-2 (RF-2)
Transect 5	Hydraulic Control
Transect 6	Run-2 (RN-2)
Transect 7	Hydraulic Control
Transect 8 (just upstream of the Route 95/128 culvert)	Riffle-3 (RF-3)

As Table 12.2-1 indicates there were three hydraulic controls in the Diversion Dam Reach. Hydraulic controls are placed at river locations where noticeable changes in velocity and depth conditions occur. An example of a hydraulic control is when the river width changes from a wide to narrow channel, which acts as a restriction (or hydraulic control) and causes water to become “backed-up”. Another type of hydraulic control occurs when the bed elevation of the channel changes quickly. The hydraulic controls are needed for the hydraulic model such that depths and velocities can be estimated for flows other than the calibration flows. It should be noted that velocity and depth data are not measured at the hydraulic controls- the only data collected and needed for the hydraulic model is the water surface elevation and cross-section data.

Total flow measurements and habitat information were collected at all transects, except at the hydraulic controls. Listed in Table 12.2-2 is a summary of the total flow measurements and velocity adjustment factors at each transect on June 4, 5, and 6. The calibration flow (shown at the bottom of Table 12.2-2) was determined by averaging the flow measurements taken at Transects 1, 2, 4, 6, and 8.

Table 12.2-2: Summary of Total Flow Measurements and Velocity Adjustment Factors at the Diversion Dam Reach on June 4, 5, and 6

	Flow (cfs) on June 4	Velocity Adjustment Factor	Flow (cfs) on June 5	Velocity Adjustment Factor	Flow (cfs) on June 6	Velocity Adjustment Factor
Transect 1	0.41	*1.05	26.79	1.04	6.92	1.18
Transect 2	0.33	1.31	29.13	0.98	8.40	0.98
Transect 3	Hydraulic Control					
Transect 4	0.47	0.92	28.39	0.98	8.96	0.91
Transect 5	Hydraulic Control					
Transect 6	0.44	0.98	28.98	0.96	7.44	1.10
Transect 7	Hydraulic Control					
Transect 8	0.51	0.85	26.77	1.04	9.26	0.89
Calibration Flow	0.43		28.00		8.20	
*- The VAF was determined as follows: 28.00 cfs/26.79 cfs= 1.05. Thus, all cellular velocities for Transect 1 were adjusted by 1.05.						

Shown in Figure 12.2-2 is the water surface profile at the Diversion Dam reach for all three calibration flows. It should be noted that the measured water surface elevations (WSE's) at Transect 7 on June 4 and 5 were in error. Therefore, the WSE's shown on Figure 12.2-2 were estimated based on the hydraulic model. As noted above, hydraulic controls are typically placed at locations where channel slope changes or the river width becomes restricted. As Figure 12.2-2 illustrates hydraulic controls were placed in areas where the channel slope (or bed elevation) changed considerably (hydraulic controls were placed at Transects 3, 5 and 7).

Included in Appendix L are the rating curves for each transect. Also shown in Appendix L are cross-section plots showing the water surface elevations for the various measured flows.

Diversion Dam Reach Calibration

As noted above, the WSP hydraulic model was used to first calibrate to observed WSE's and then to observed cellular velocities. The hydraulic model was calibrated to the middle (8.2 cfs) and high (28.0 cfs) flow, but could not be calibrated to the low flow (0.43 cfs). Calibration of the hydraulic model to low flow conditions was not possible due to two-dimensional flow patterns that occurred and the inability to balance energy between transects—in summary, the flow was simply too low for modeling.

Shown in Table 12.2-3 is the predicted and observed WSE's for the calibration flows (8.2 and 28.0 cfs) at each transect.

Table 12.2-3: Diversion Dam Reach, Water Surface Elevation Calibration Results

	Transect 1	Transect 2	Transect 3	Transect 4	Transect 5	Transect 6	Transect 7	Transect 8
Calibration Flow= 8.2 cfs								
Observed Elev (ft)	92.15	91.88	91.71	91.45	91.00	91.00	90.98	90.53
Predicted Elev (ft)	92.15	91.87	91.68	91.42	91.04	91.00	90.99	90.53
Difference	0.00	-0.01	-0.03	-0.03	0.04	0.00	0.01	0.00
Calibration Flow= 28.0 cfs								
Observed Elev (ft)	92.75	92.23	92.01	91.86	91.50	91.50	91.43	90.89
Predicted Elev (ft)	92.74	92.19	92.05	91.84	91.52	91.47	91.43	90.89
Difference	-0.01	-0.04	0.04	-0.02	0.02	-0.03	0.00	0.00
Note: The elevations above are relative to a fixed benchmark datum of 100.0 feet								

As Table 12.2-3 shows the WSE calibration was well within the acceptable tolerance of 0.1 feet difference between the predicted and observed elevations. The calibration to cellular velocities was also considered good- the results are provided in Table 12.2-4 at the end of this section. In some instances the measured and predicted cellular velocity varied by more than 0.1 feet/second, with most of these occurring in cells along the river's edge, which is not uncommon. When in the field there were many instances where there was sufficient depth in a cell near the river's edge, however, the measured velocity in the cell was zero (and in some cases the velocity was "negative" when back eddies occur). In the hydraulic model, water flows through these edge cells and the model will assume some velocity. Thus, the measured velocity (0 ft/sec) and predicted velocity will vary more 0.1 feet/second. Within the hydraulic model, it is possible to artificially set the Mannings "n" in this cell to a high value, which will result in reducing the velocity through the cell (thus forcing the model velocity to be closer to the measured velocity of 0 ft/sec). However, it should be noted that a hydraulic model simulates flows above and below the calibration flow. By setting an artificially high Mannings "n" value it will also produce unrealistic velocities under high flow conditions and could also affect the predicted WSE. Given this, Mannings "n" values were not changed, but were representative of the stream characteristics.

As noted earlier, the hydraulic model will allow habitat conditions to be predicted at 40-250% of the calibration flow. The calibration flows and flow ranges are shown in Table 12.2-5.

Table 12.2-5: Range of Flows Used to Simulate Habitat Conditions at the Diversion Dam

Calibration Flow	40% of Calibration Flow	250% of Calibration Flow
0.43 cfs	As described above, the low flow (0.43 cfs) could not be simulated in the hydraulic model, thus habitat conditions at 40-250% of 0.43 cfs were not quantified.	
8.20 cfs	3.3 cfs	20.5 cfs
28.00 cfs	11.2 cfs	70.0 cfs

As Table 12.2-5 shows, there is sufficient overlap between the middle (8.2 cfs) and high flow (28.0 cfs) to cover the range of habitat conditions from 3.3 cfs to 70.0 cfs. The range of habitat conditions also covers the range of expected flows in the watershed. Shown in Figure 12.2-3 is the average annual hydrograph at the Saugus River USGS gage along with the range of flows examined in this study.

12.3 Results of Hydraulic Model Calibration for the Staples Reach

The Staples Reach is located a few hundred feet below the Staples store on Route 1 in Saugus. The Staples Reach (approximately 292 feet) was similar to the Diversion Dam Reach in that habitat types were primarily riffle and run, with gravel, cobble, and small boulder substrates. However, the riffles and runs were deeper and had slower velocities as compared to the Diversion Dam Reach. Generally there were few velocity refuges available; however, there were a handful of areas containing small boulders, which provided some velocity refuge. All substrates were highly embedded with fine material.

Shown in Figure 12.3-1 is a plan map showing the river's edge, and five transects in the Staples Reach. Table 12.3-1 lists the habitat types where the transects were placed. Similar to the Diversion Dam Reach, habitat types were identified during the July 18-21, 2000 habitat mapping exercise.

Table 12.3-1: Transect Location relative to Habitat Types (Staples Reach)

Transect 1 (upstream most transect)	Riffle 1 (RF-1)
Transect 2	Run 1 (RN-1)
Transect 3	Hydraulic Control
Transect 4	Riffle 2 (RF-2)
Transect 5	Run 2 (RN-2)

Total flow measurements and habitat information were collected at all transects, except at the hydraulic control. Listed in Table 12.3-2 is a summary of the total flow measurements and velocity adjustment factors at each transect on June 5 and July 31 (note that data collected on June 4 was not used in the hydraulic model because of unstable flow conditions). The calibration flow (see bottom of Table 12.3-2) was computed as the average flow based on flow measurements taken at Transects 1, 2, 4, and 5.

Table 12.3-2: Summary of Total Flow Measurements and Velocity Adjustment Factors at the Staples Reach on June 5 and July 31.

	Flow (cfs) on June 5	Velocity Adjustment Factor	Flow (cfs) on July 31	Velocity Adjustment Factor
Transect 1	25.16	0.96	3.8	0.96
Transect 2	20.80	1.16	2.9	1.26
Transect 3	-	-	-	-
Transect 4	24.13	1.00	4.4	0.83
Transect 5	26.33	0.92	3.5	1.04
Calibration Flow	24.11	-	3.65	-

Shown in Figure 12.3-2 is the water surface profile of the Staples Reach for two calibration flows. It should be noted that Transect 3 was placed at a hydraulic control, where the river gradient drops quickly over a short distance. Because the river gradient dropped so quickly over a short distance, two hydraulic models were developed, one from Transect 5 to 3 and the other from Transect 3 to 1.

Staples Reach Calibration

Similar to the Diversion Dam Reach, the WSP hydraulic model was first calibrated to observed WSE's and then to observed cellular velocities. The hydraulic model was calibrated to flows of 3.65 cfs and 24.1 cfs. Shown in Table 12.3-3 are the predicted and observed WSE's for the calibration flows (3.65 and 24.1 cfs) at each transect.

Table 12.3-3: Staples Reach, WSE Calibration Results

	Transect 1	Transect 2	Transect 3	Transect 4	Transect 5
Calibration Flow= 3.65 cfs					
Observed Elev (ft)	213.57	213.56	213.54	213.08	212.82
Predicted Elev (ft)	213.55	213.55	213.54	212.98	212.92
Difference	-0.02	-0.01	0.00	-0.10	+0.10
Calibration Flow=24.1 cfs					
Observed Elev (ft)	214.16	214.06	214.02	213.55	213.47
Predicted Elev (ft)	214.14	214.07	214.02	213.54	213.43
Difference	-0.02	+0.01	0.00	-0.01	-0.04
Note: The elevations above are relative to a fixed benchmark datum of 200.0 feet					

As Table 12.3-3 shows, the WSE calibration was within the acceptable tolerance of 0.1 feet difference between the predicted and observed elevations. The calibration to cellular velocities was also conducted and the results provided at the end of this section. In general, calibration to WSE's and cellular velocities was good (although calibration of the low flow model was more difficult). Shown in Table 12.3-4 are the velocity calibration results (see end of section).

As noted above, the hydraulic model will allow habitat conditions to be quantified at 40-250% of the calibration flow. The calibration flows and flow ranges are shown in Table 12.3-5.

Table 12.3-5: Range of Flows Used to Simulate Habitat Conditions at Staples Reach

Calibration Flow	40% of Calibration Flow	250% of Calibration Flow
3.65 cfs	1.5 cfs	9.1 cfs
24.10 cfs	9.6 cfs	60.2 cfs

As Table 12.3-5 shows, there is a slight gap between the low and high flow models at 9 cfs. Shown on Figure 12.2-3 is the range of flows covered by the habitat model relative to the annual hydrograph. Again, the calibration flows cover a large portion of the annual hydrograph.

TABLE 12.2-4:
DIVERSION DAM, VELOCITY CALIBRATION RESULTS FOR MIDDLE FLOW (8.2 CFS)

Transect 1			Transect 2			Transect 4			Transect 6			Transect 8		
Observed Velocity VAF=1.18 (ft/sec)	Predicted Velocity (ft/sec)	Predicted-Observed (ft/sec)	Observed Velocity VAF=0.98 (ft/sec)	Predicted Velocity (ft/sec)	Predicted-Observed (ft/sec)	Observed Velocity VAF=0.91 (ft/sec)	Predicted Velocity (ft/sec)	Predicted-Observed (ft/sec)	Observed Velocity VAF=1.10 (ft/sec)	Predicted Velocity (ft/sec)	Predicted-Observed (ft/sec)	Observed Velocity VAF=0.89 (ft/sec)	Predicted Velocity (ft/sec)	Predicted-Observed (ft/sec)
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.21	0.21	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.42	0.42	0.00	0.04	0.04	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.53	0.53	0.03	0.08	0.05	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.57	0.57	0.09	0.09	0.00	0.00	0.00	0.00
0.17	0.17	0.00	0.00	0.00	0.00	0.00	0.57	0.57	0.18	0.16	-0.02	0.00	0.00	0.00
0.42	0.44	0.02	0.00	0.00	0.00	0.00	0.58	0.58	0.28	0.25	-0.03	0.00	0.00	0.00
0.27	0.35	0.08	0.00	0.00	0.00	0.08	0.72	0.64	0.37	0.32	-0.05	0.00	0.00	0.00
0.10	0.37	0.27	0.34	0.31	-0.03	0.41	0.76	0.35	0.50	0.45	-0.05	0.00	0.00	0.00
0.31	0.38	0.07	0.68	0.64	-0.04	0.78	0.79	0.01	0.64	0.58	-0.06	0.00	0.00	0.00
0.42	0.43	0.01	0.84	0.80	-0.04	1.11	1.11	0.00	0.76	0.68	-0.08	0.00	0.00	0.00
0.49	0.50	0.01	0.98	0.97	-0.01	1.38	1.40	0.02	0.91	0.89	-0.02	0.00	0.00	0.00
0.68	0.70	0.02	1.14	1.14	0.00	1.84	1.89	0.05	0.98	0.93	-0.05	0.00	0.00	0.00
0.99	1.01	0.02	1.19	1.18	-0.01	2.35	2.35	0.00	1.06	0.99	-0.07	0.00	0.21	0.21
1.23	1.25	0.02	1.14	1.13	-0.01	2.19	2.22	0.03	1.05	1.03	-0.01	0.60	0.58	-0.02
1.47	1.48	0.01	1.32	1.31	-0.01	2.06	2.08	0.02	0.84	0.79	-0.05	0.89	0.88	-0.01
0.84	0.85	0.01	1.08	1.08	0.00	2.16	2.17	0.01	0.62	0.56	-0.06	0.40	0.39	-0.01
0.00	0.41	0.41	0.77	0.78	0.01	2.12	2.13	0.01	0.46	0.41	-0.05	0.33	0.40	0.07
0.25	0.46	0.21	1.06	1.04	-0.02	2.11	2.13	0.02	0.37	0.33	-0.04	0.57	0.57	0.00
1.40	1.43	0.03	1.42	1.40	-0.02	1.82	1.84	0.02	0.26	0.24	-0.02	0.77	0.76	-0.01
1.96	1.99	0.03	1.27	1.27	0.00	1.39	1.41	0.02	0.19	0.19	0.00	0.88	0.83	-0.05
1.37	1.40	0.03	1.34	1.33	-0.01	1.16	1.18	0.02	0.18	0.19	0.01	1.06	1.05	-0.01
1.32	1.35	0.03	1.51	1.49	-0.02	1.10	1.11	0.01	0.13	0.19	0.06	1.31	1.28	-0.03
1.44	1.46	0.02	1.30	1.30	0.00	1.17	1.19	0.02	0.06	0.17	0.12	1.70	1.68	-0.02
1.20	1.22	0.02	1.27	1.26	-0.01	1.05	1.07	0.02	0.03	0.16	0.13	2.06	1.99	-0.07
0.97	0.98	0.01	1.37	1.36	-0.01	0.81	0.82	0.01	0.05	0.15	0.10	2.51	2.51	0.00
0.81	0.83	0.02	1.48	1.46	-0.02	0.76	0.77	0.01	0.04	0.15	0.11	2.73	2.75	0.02
0.74	0.75	0.01	1.29	1.29	0.00	0.56	0.56	0.00	0.01	0.14	0.13	2.00	2.01	0.01
0.72	0.73	0.01	0.94	0.93	-0.01	0.33	0.44	0.11	0.03	0.11	0.08	1.28	1.27	-0.01
0.71	0.72	0.01	0.95	0.95	0.00	0.18	0.44	0.26	0.03	0.09	0.06	1.06	1.05	-0.01
0.71	0.72	0.01	1.16	1.15	-0.01	0.10	0.44	0.34	0.01	0.05	0.04	0.81	0.81	0.00
0.58	0.60	0.02	1.18	1.17	-0.01	0.11	0.44	0.33	0.00	0.00	0.00	0.70	0.65	-0.05
0.37	0.38	0.01	1.35	1.34	-0.01	0.10	0.39	0.29	0.00	0.00	0.00	0.74	0.74	0.00
0.22	0.22	0.00	1.09	0.38	-0.71	0.05	0.16	0.11	0.00	0.00	0.00	0.65	0.61	-0.04
0.09	0.14	0.05	0.31	0.46	0.15	0.00	0.00	0.00				0.56	0.52	-0.04
0.00	0.16	0.16	0.00	0.47	0.47	0.00	0.00	0.00				0.57	0.53	-0.04
0.00	0.19	0.19	0.00	0.47	0.47	0.00	0.00	0.00				0.53	0.54	0.01
0.00	0.13	0.13	0.12	0.48	0.36							0.25	0.31	0.06
0.00	0.04	0.04	0.49	0.81	0.32							0.02	0.16	0.14
0.00	0.00	0.00	0.82	0.84	0.02							0.00	0.00	0.00
0.00	0.00	0.00	0.84	0.76	-0.08							0.00	0.00	0.00
0.00	0.00	0.00	0.76	0.48	-0.28							0.00	0.00	0.00
0.00	0.00	0.00	0.48	0.37	-0.11							0.00	0.00	0.00
0.00	0.00	0.00	0.37	0.40	0.03							0.00	0.00	0.00
0.00	0.00	0.00	0.40	0.25	-0.15							0.00	0.00	0.00
0.00	0.00	0.00	0.13	0.14	0.01							0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.06	0.06									
			0.00	0.00	0.00									
			0.00	0.00	0.00									
			0.00	0.00	0.00									
			0.00	0.00	0.00									
			0.00	0.00	0.00									

TABLE 12.2-4:
DIVERSION DAM, VELOCITY CALIBRATION RESULTS FOR HIGH FLOW (28.0 CFS)

Transect 1			Transect 2			Transect 4			Transect 6			Transect 8		
Observed Velocity VAF=1.05 (ft/sec)	Predicted Velocity (ft/sec)	Predicted-Observed (ft/sec)	Observed Velocity VAF=0.96 (ft/sec)	Predicted Velocity (ft/sec)	Predicted-Observed (ft/sec)	Observed Velocity VAF=0.99 (ft/sec)	Predicted Velocity (ft/sec)	Predicted-Observed (ft/sec)	Observed Velocity VAF=0.97 (ft/sec)	Predicted Velocity (ft/sec)	Predicted-Observed (ft/sec)	Observed Velocity VAF=1.05 (ft/sec)	Predicted Velocity (ft/sec)	Predicted-Observed (ft/sec)
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.30	0.15	0.00	0.01	0.01	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.31	0.55	0.24	0.10	0.10	0.00	0.00	0.00	0.00
0.18	0.20	0.02	0.00	0.00	0.00	0.29	0.73	0.44	0.18	0.19	0.01	0.00	0.00	0.00
0.48	0.54	0.06	0.00	0.00	0.00	0.66	0.79	0.13	0.22	0.22	0.00	0.00	0.00	0.00
0.64	0.71	0.07	0.00	0.00	0.00	0.84	0.83	-0.01	0.36	0.37	0.01	0.00	0.00	0.00
0.81	0.89	0.08	0.00	0.00	0.00	0.46	0.85	0.39	0.53	0.53	0.00	0.00	0.00	0.00
0.47	0.65	0.18	0.14	0.18	0.04	0.50	0.90	0.40	0.70	0.70	0.00	0.00	0.00	0.00
0.17	0.85	0.68	0.39	0.37	-0.02	1.18	1.19	0.01	0.86	0.87	0.01	0.00	0.00	0.00
1.01	1.04	0.03	0.82	0.82	0.00	1.88	1.90	0.02	0.99	0.99	0.00	0.00	0.00	0.00
1.35	1.39	0.04	1.20	1.21	0.01	2.10	2.11	0.01	1.08	1.08	0.00	0.00	0.00	0.00
1.21	1.24	0.03	0.94	0.95	0.01	2.70	2.74	0.04	1.07	1.07	0.00	0.00	0.00	0.00
1.63	1.68	0.05	1.20	1.22	0.02	3.09	3.10	0.01	1.18	1.19	0.01	0.00	0.00	0.00
2.07	2.07	0.00	1.90	1.91	0.01	3.09	3.14	0.05	1.41	1.43	0.02	1.22	1.21	-0.01
2.07	2.08	0.01	2.08	2.10	0.02	3.16	3.21	0.05	1.57	1.55	-0.02	2.46	2.46	0.00
2.12	2.13	0.01	2.31	2.34	0.03	2.76	2.80	0.04	1.64	1.66	0.02	2.00	2.02	0.02
2.26	2.27	0.01	2.29	2.33	0.04	2.93	2.96	0.03	1.69	1.69	0.00	1.82	1.81	-0.01
2.38	2.39	0.01	2.03	2.05	0.02	3.11	3.16	0.05	1.61	1.64	0.03	2.34	2.34	0.00
2.63	2.64	0.01	2.17	2.20	0.03	2.70	2.74	0.04	1.54	1.55	0.01	1.92	1.93	0.01
2.34	2.33	-0.01	2.47	2.49	0.02	2.83	2.86	0.03	1.53	1.55	0.02	1.49	1.49	0.00
1.84	1.89	0.05	2.76	2.81	0.05	3.01	3.03	0.02	1.35	1.36	0.01	2.11	2.11	0.00
1.66	1.71	0.05	2.76	2.79	0.03	2.90	2.93	0.03	1.12	1.13	0.01	2.93	2.92	-0.01
1.61	1.65	0.04	2.65	2.64	-0.01	2.96	2.98	0.02	0.99	1.00	0.01	3.77	3.72	-0.05
1.52	1.55	0.03	2.86	2.85	-0.01	2.98	3.02	0.04	0.96	0.96	0.00	4.12	4.07	-0.05
1.35	1.40	0.05	2.67	2.64	-0.03	2.80	2.82	0.02	0.84	0.85	0.01	3.86	3.78	-0.08
1.30	1.34	0.04	2.36	2.39	0.03	2.25	2.26	0.01	0.57	0.57	0.00	3.25	3.19	-0.06
1.44	1.48	0.04	2.36	2.42	0.06	1.72	1.74	0.02	0.34	0.34	0.00	2.97	2.95	-0.02
1.50	1.53	0.03	2.20	2.23	0.03	1.65	1.67	0.02	0.28	0.28	0.00	3.09	3.03	-0.06
1.86	1.91	0.05	2.39	2.40	0.01	1.51	1.52	0.01	0.27	0.27	0.00	2.29	2.29	0.00
2.10	2.10	0.00	2.78	2.81	0.03	1.06	1.06	0.00	0.13	0.18	0.05	2.27	2.28	0.01
1.93	1.91	-0.02	2.64	2.67	0.03	0.47	0.79	0.32	0.00	0.12	0.12	2.44	2.44	0.00
1.82	1.79	-0.03	2.34	2.34	0.00	0.05	0.74	0.69	0.00	0.09	0.09	1.82	1.82	0.00
1.52	1.56	0.04	2.21	2.25	0.04	0.00	0.35	0.35	0.00	0.01	0.01	1.92	1.93	0.01
1.17	1.19	0.02	1.52	1.54	0.02	0.00	0.12	0.12	0.00	0.00	0.00	1.96	1.96	0.00
0.86	0.88	0.02	0.41	0.48	0.07	0.00	0.07	0.07				1.56	1.57	0.01
0.78	0.79	0.01	0.03	0.47	0.44	0.00	0.00	0.00				1.32	1.32	0.00
0.59	0.65	0.06	0.00	0.48	0.48	0.00	0.00	0.00				1.21	1.21	0.00
0.42	0.64	0.22	0.55	0.55	0.00							0.82	0.82	0.00
0.36	0.55	0.19	1.78	1.79	0.01							0.44	0.74	0.30
0.12	0.46	0.34	2.32	2.33	0.01							0.13	0.57	0.44
0.00	0.38	0.38	1.90	1.92	0.02							0.00	0.43	0.43
0.00	0.19	0.19	1.59	1.61	0.02							0.00	0.43	0.43
0.00	0.00	0.00	1.47	1.50	0.03							0.00	0.43	0.43
0.00	0.00	0.00	1.26	1.27	0.01							0.00	0.37	0.37
0.00	0.00	0.00	0.99	1.00	0.01							0.00	0.37	0.37
0.00	0.00	0.00	0.72	0.73	0.01							0.00	0.21	0.21
0.00	0.00	0.00	0.55	0.56	0.01									
			0.33	0.33	0.00									
			0.07	0.16	0.09									
			0.00	0.00	0.00									
			0.00	0.00	0.00									
			0.00	0.00	0.00									

TABLE 12.3-4:
STAPLES REACH, VELOCITY CALIBRATION RESULTS FOR LOW FLOW (3.65 CFS)

Transect 1			Transect 2			Transect 4			Transect 5		
Observed Velocity VAF=0.96 (ft/sec)	Predicted Velocity (ft/sec)	Predicted-Observed (ft/sec)	Observed Velocity VAF=1.26 (ft/sec)	Predicted Velocity (ft/sec)	Predicted-Observed (ft/sec)	Observed Velocity VAF=0.83 (ft/sec)	Predicted Velocity (ft/sec)	Predicted-Observed (ft/sec)	Observed Velocity VAF=1.04 (ft/sec)	Predicted Velocity (ft/sec)	Predicted-Observed (ft/sec)
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.24	0.00	0.01	0.01
0.00	0.01	0.01	0.00	0.03	0.03	0.40	0.51	0.11	0.00	0.01	0.01
0.00	0.01	0.01	0.00	0.05	0.05	1.32	0.97	-0.35	0.00	0.02	0.02
0.02	0.03	0.01	0.00	0.08	0.08	1.68	1.24	-0.44	0.00	0.04	0.04
0.02	0.07	0.05	0.00	0.08	0.08	1.15	0.84	-0.31	0.00	0.05	0.05
0.00	0.08	0.08	0.00	0.08	0.08	0.58	0.43	-0.15	0.06	0.05	-0.01
0.00	0.09	0.09	0.00	0.08	0.08	0.38	0.31	-0.07	0.23	0.13	-0.10
0.00	0.10	0.10	0.00	0.07	0.07	0.33	0.27	-0.06	0.37	0.22	-0.15
0.01	0.10	0.09	0.02	0.10	0.08	0.65	0.45	-0.20	0.42	0.25	-0.17
0.12	0.11	-0.01	0.03	0.10	0.07	1.03	0.40	-0.63	0.44	0.26	-0.18
0.46	0.44	-0.02	0.03	0.06	0.03	0.85	0.37	-0.48	0.38	0.23	-0.15
0.58	0.55	-0.03	0.05	0.06	0.01	0.36	0.00	-0.36	0.37	0.20	-0.17
0.67	0.64	-0.03	0.06	0.05	-0.01	0.06	0.00	-0.06	0.45	0.25	-0.20
0.79	0.75	-0.04	0.12	0.10	-0.02	0.06	0.00	-0.06	0.35	0.19	-0.16
0.55	0.52	-0.03	0.23	0.21	-0.02	0.06	0.00	-0.06	0.25	0.14	-0.11
0.28	0.26	-0.02	0.31	0.27	-0.04	0.03	0.00	-0.03	0.22	0.12	-0.10
0.11	0.10	-0.01	0.35	0.30	-0.05	0.00	0.00	0.00	0.13	0.07	-0.06
0.10	0.09	-0.01	0.40	0.35	-0.05	0.00	0.00	0.00	0.06	0.06	0.00
0.16	0.15	-0.01	0.46	0.41	-0.05	0.00	0.00	0.00	0.03	0.07	0.04
0.17	0.16	-0.01	0.44	0.37	-0.07	0.00	0.00	0.00	0.00	0.07	0.07
0.27	0.26	-0.01	0.39	0.35	-0.04	0.00	0.00	0.00	0.00	0.07	0.07
0.63	0.64	0.01	0.42	0.38	-0.04	0.00	0.00	0.00	0.00	0.08	0.08
0.43	0.38	-0.05	0.46	0.40	-0.06	0.00	0.00	0.00	0.00	0.07	0.07
0.00	0.03	0.03	0.50	0.43	-0.07	0.00	0.00	0.00	0.00	0.07	0.07
0.00	0.00	0.00	0.43	0.36	-0.07	0.00	0.00	0.00	0.00	0.06	0.06
0.00	0.00	0.00	0.41	0.36	-0.05	0.00	0.00	0.00	0.00	0.05	0.05
0.00	0.00	0.00	0.45	0.39	-0.06	0.00	0.00	0.00	0.00	0.04	0.04
			0.42	0.37	-0.05	0.00	0.00	0.00	0.00	0.01	0.01
			0.39	0.34	-0.05	0.00	0.00	0.00	0.00	0.00	0.00
			0.26	0.23	-0.03	0.00	0.00	0.00	0.00	0.00	0.00
			0.07	0.07	0.00	0.00	0.00	0.00			
			0.00	0.06	0.06	0.00	0.00	0.00			
			0.03	0.06	0.03	0.08	0.00	-0.08			
			0.03	0.05	0.02	0.08	0.00	-0.08			
			0.00	0.04	0.04	0.00	0.00	0.00			
			0.00	0.02	0.02	0.00	0.06	0.06			
			0.00	0.01	0.01	0.00	0.05	0.05			
			0.00	0.00	0.00	0.00	0.00	0.00			
			0.00	0.00	0.00	0.00	0.00	0.00			
			0.00	0.00	0.00	0.00	0.00	0.00			
						0.00	0.00	0.00			
						0.00	0.00	0.00			
						0.00	0.00	0.00			
						0.00	0.00	0.00			
						0.00	0.00	0.00			

TABLE 12.3-4:
STAPLES REACH, VELOCITY CALIBRATION RESULTS FOR HIGH FLOW (24.1 CFS)

Transect 1			Transect 2			Transect 4			Transect 5		
Observed Velocity VAF=0.96 (ft/sec)	Predicted Velocity (ft/sec)	Predicted-Observed (ft/sec)	Observed Velocity VAF=1.16 (ft/sec)	Predicted Velocity (ft/sec)	Predicted-Observed (ft/sec)	Observed Velocity VAF=1.00 (ft/sec)	Predicted Velocity (ft/sec)	Predicted-Observed (ft/sec)	Observed Velocity VAF=0.92 (ft/sec)	Predicted Velocity (ft/sec)	Predicted-Observed (ft/sec)
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.03	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
0.08	0.14	0.06	0.00	0.04	0.04	0.00	0.36	0.36	0.00	0.03	0.03
0.17	0.25	0.08	0.00	0.09	0.09	0.29	0.75	0.46	0.00	0.04	0.04
0.22	0.22	0.00	0.10	0.12	0.02	0.87	0.89	0.03	0.00	0.04	0.04
0.48	0.48	0.00	0.38	0.38	0.00	0.93	0.96	0.03	0.00	0.07	0.07
0.48	0.48	0.00	0.64	0.64	0.00	1.08	1.12	0.04	0.00	0.08	0.08
0.26	0.43	0.17	0.86	0.87	0.01	1.48	1.52	0.04	0.17	0.15	-0.02
0.38	0.47	0.09	1.03	1.03	0.00	1.35	1.41	0.06	0.59	0.54	-0.05
0.36	0.49	0.13	0.88	0.86	-0.02	1.31	1.34	0.04	1.08	1.01	-0.07
0.59	0.60	0.01	0.71	0.71	0.00	1.54	1.59	0.06	1.40	1.33	-0.07
0.74	0.75	0.01	0.72	0.73	0.01	1.68	1.68	0.00	1.47	1.49	0.02
0.76	0.77	0.01	0.77	0.78	0.01	1.76	1.80	0.05	1.45	1.35	-0.10
1.14	1.15	0.01	0.88	0.89	0.01	1.75	1.80	0.05	1.39	1.39	0.00
1.32	1.33	0.01	0.96	0.97	0.01	1.66	1.70	0.04	1.35	1.28	-0.07
1.94	1.99	0.05	1.02	1.02	0.01	1.70	1.70	0.00	1.31	1.28	-0.03
2.59	2.66	0.07	1.04	1.04	0.00	1.82	1.84	0.03	1.27	1.18	-0.09
2.40	2.43	0.03	1.11	1.10	-0.01	1.82	1.87	0.05	1.23	1.18	-0.05
2.04	2.07	0.03	1.18	1.16	-0.02	1.80	1.83	0.03	1.15	1.09	-0.06
2.27	2.27	0.00	1.26	1.27	0.01	1.75	1.76	0.01	0.93	0.86	-0.07
1.62	1.64	0.02	1.39	1.36	-0.03	1.74	1.80	0.06	0.66	0.61	-0.05
0.82	0.84	0.02	1.42	1.43	0.01	1.79	1.83	0.04	0.41	0.37	-0.04
1.61	1.62	0.01	1.35	1.34	-0.01	1.83	1.84	0.02	0.13	0.11	-0.02
1.72	1.72	0.00	1.19	1.21	0.02	1.80	1.84	0.04	0.00	0.12	0.12
0.95	0.97	0.02	1.21	1.21	0.00	1.81	1.84	0.04	0.00	0.12	0.12
0.33	0.33	0.00	1.24	1.21	-0.03	1.83	1.84	0.01	0.00	0.11	0.11
0.00	0.12	0.12	1.17	1.20	0.03	1.79	1.83	0.04	0.00	0.09	0.09
0.00	0.00	0.00	1.18	1.19	0.01	1.89	1.94	0.05	0.00	0.08	0.08
0.00	0.00	0.00	1.10	1.13	0.03	1.90	1.91	0.01	0.00	0.06	0.06
			0.95	0.93	-0.02	1.82	1.83	0.02	0.00	0.01	0.01
			0.85	0.86	0.01	1.80	1.80	0.01	0.00	0.00	0.00
			0.71	0.71	0.00	1.79	1.80	0.02	0.00	0.00	0.00
			0.43	0.42	-0.01	1.84	1.80	-0.03			
			0.19	0.19	0.00	1.79	1.87	0.08			
			0.08	0.13	0.05	1.59	1.59	0.00			
			0.08	0.11	0.03	1.42	1.48	0.06			
			0.07	0.09	0.02	1.06	1.11	0.05			
			0.02	0.09	0.07	0.62	0.64	0.03			
			0.00	0.04	0.04	0.38	0.40	0.02			
			0.00	0.00	0.00	0.19	0.20	0.02			
			0.00	0.00	0.00	0.04	0.19	0.15			
			0.00	0.00	0.00	0.00	0.11	0.11			
						0.00	0.00	0.00			
						0.00	0.00	0.00			
						0.00	0.12	0.12			
						0.00	0.09	0.09			
						0.00	0.00	0.00			

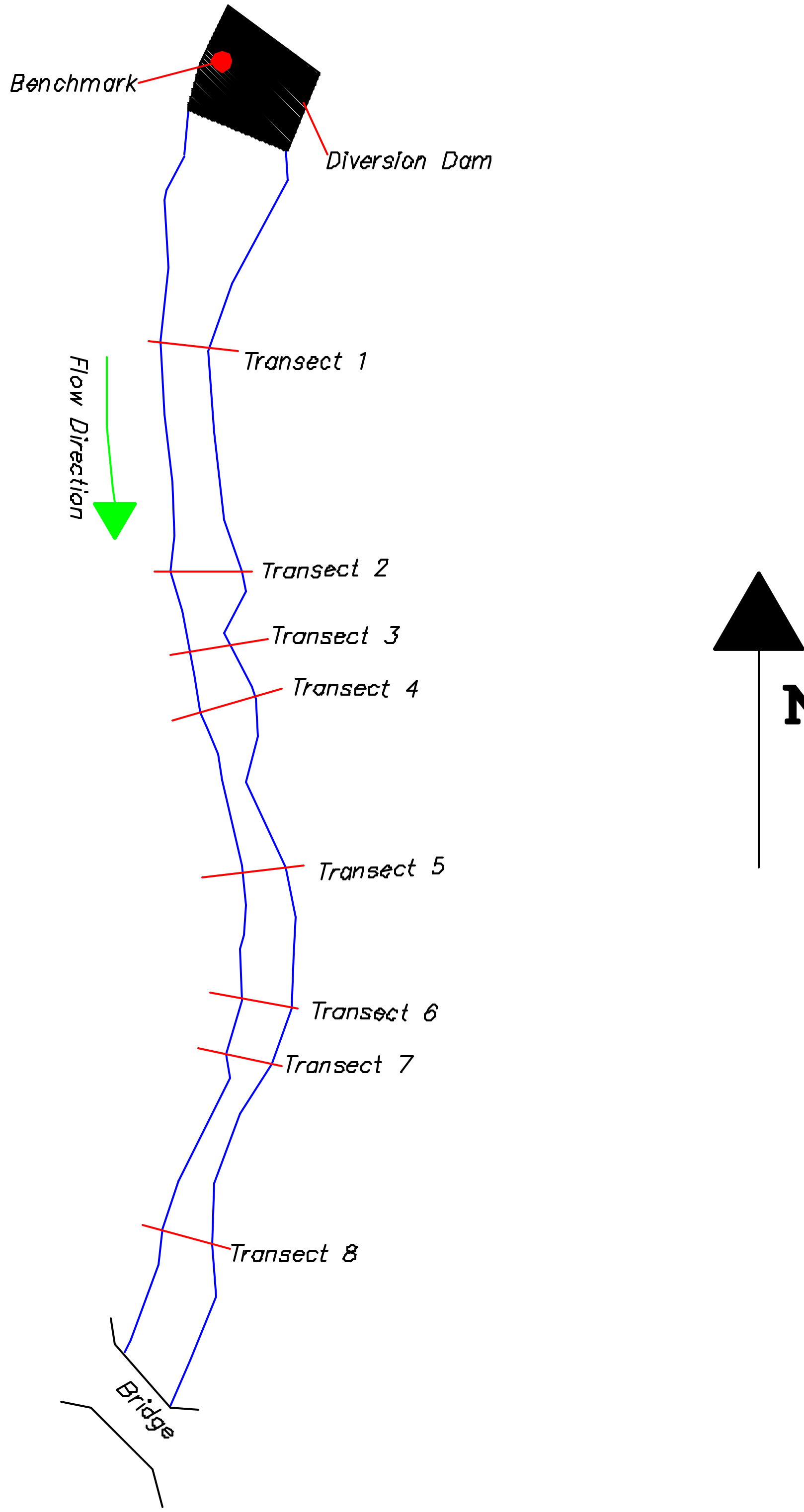


FIGURE 12.2-1
PLAN VIEW OF DIVERSION DAM
REACH SHOWING TRANSECT LOCATIONS
SCALE 1" = 40 '

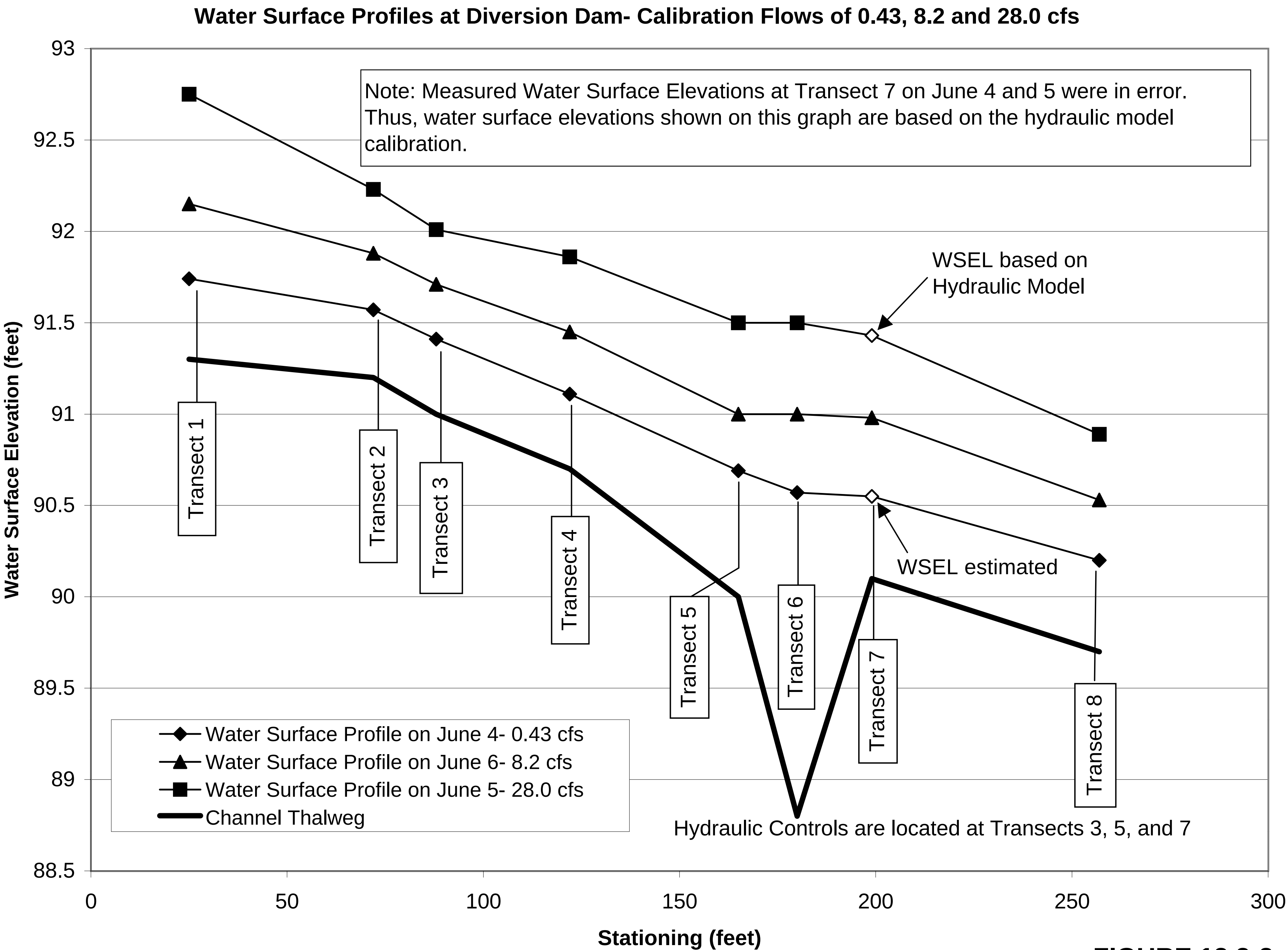

Water Surface Profiles at Diversion Dam- Calibration Flows of 0.43, 8.2 and 28.0 cfs
Note: Measured Water Surface Elevations at Transect 7 on June 4 and 5 were in error. Thus, water surface elevations shown on this graph are based on the hydraulic model calibration.
WSEL based on Hydraulic Model
WSEL estimated
Transect 1
Transect 2
Transect 3
Transect 4
Transect 5
Transect 6
Transect 7
Transect 8
Water Surface Profile on June 4- 0.43 cfs
Water Surface Profile on June 6- 8.2 cfs
Water Surface Profile on June 5- 28.0 cfs
Channel Thalweg
Hydraulic Controls are located at Transects 3, 5, and 7
Water Surface Elevation (feet)
93
92.5
92
91.5
91
90.5
90
89.5
89
88.5
0
50
100
150
200
250
300
Stationing (feet)

FIGURE 12.2-2

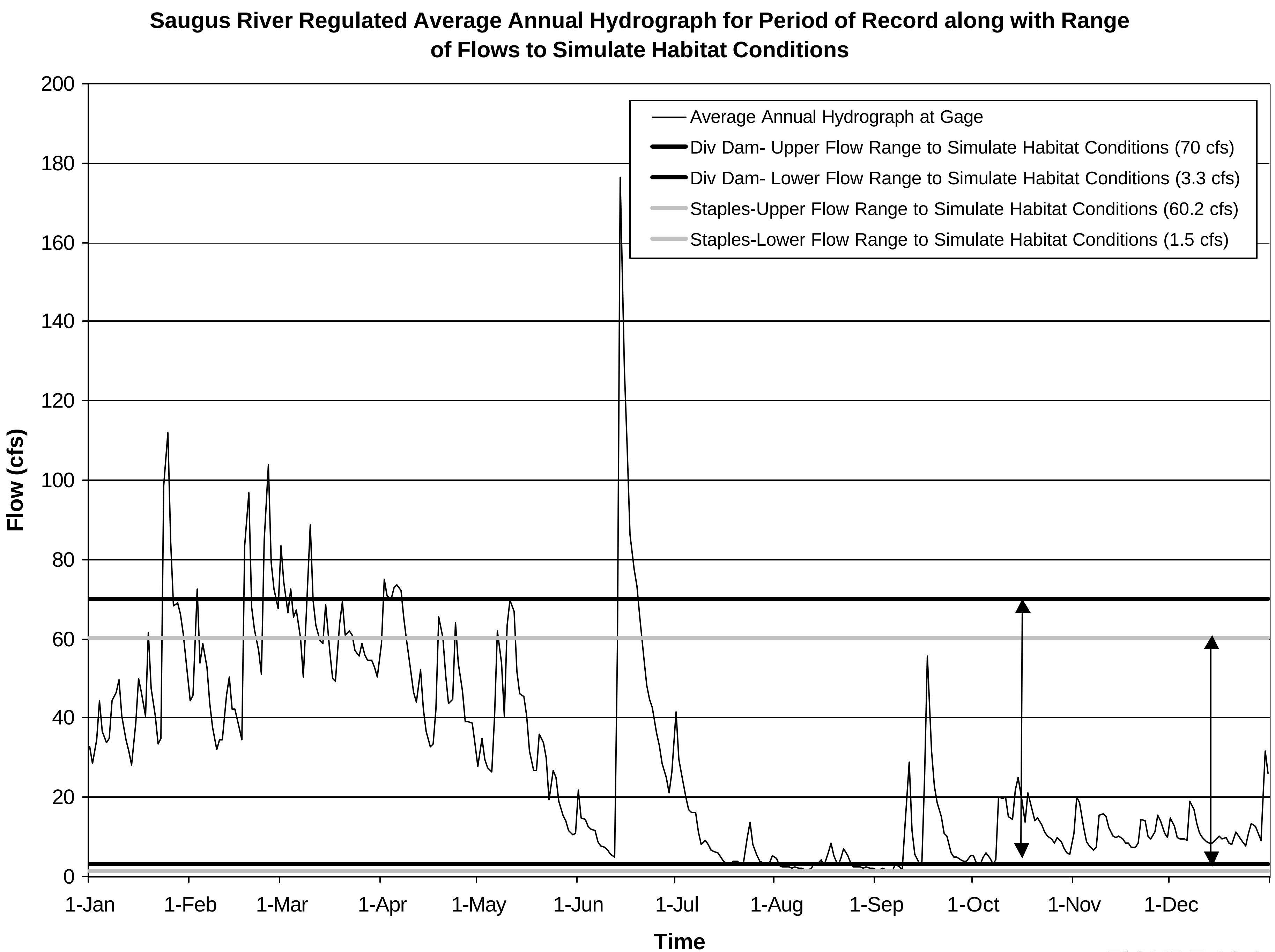

Saugus River Regulated Average Annual Hydrograph for Period of Record along with Range of Flows to Simulate Habitat Conditions
Average Annual Hydrograph at Gage
Div Dam- Upper Flow Range to Simulate Habitat Conditions (70 cfs)
Div Dam- Lower Flow Range to Simulate Habitat Conditions (3.3 cfs)
Staples-Upper Flow Range to Simulate Habitat Conditions (60.2 cfs)
Staples-Lower Flow Range to Simulate Habitat Conditions (1.5 cfs)
Flow (cfs)
200
180
160
140
120
100
80
60
40
20
0
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
Time

FIGURE 12.2-3

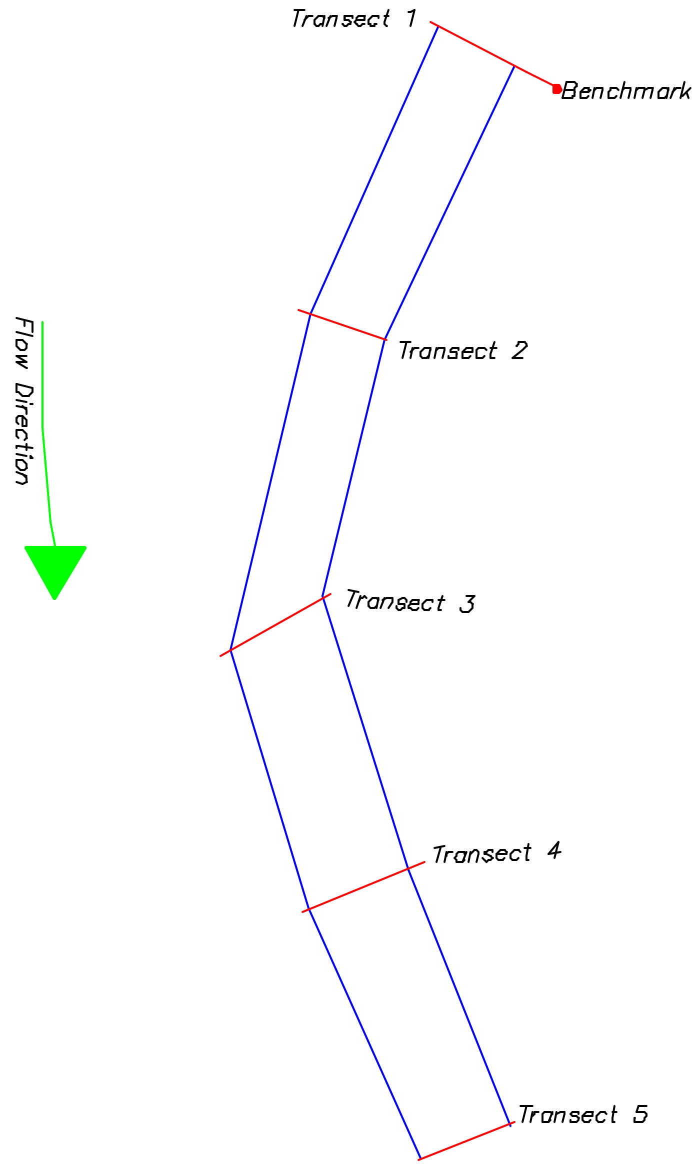
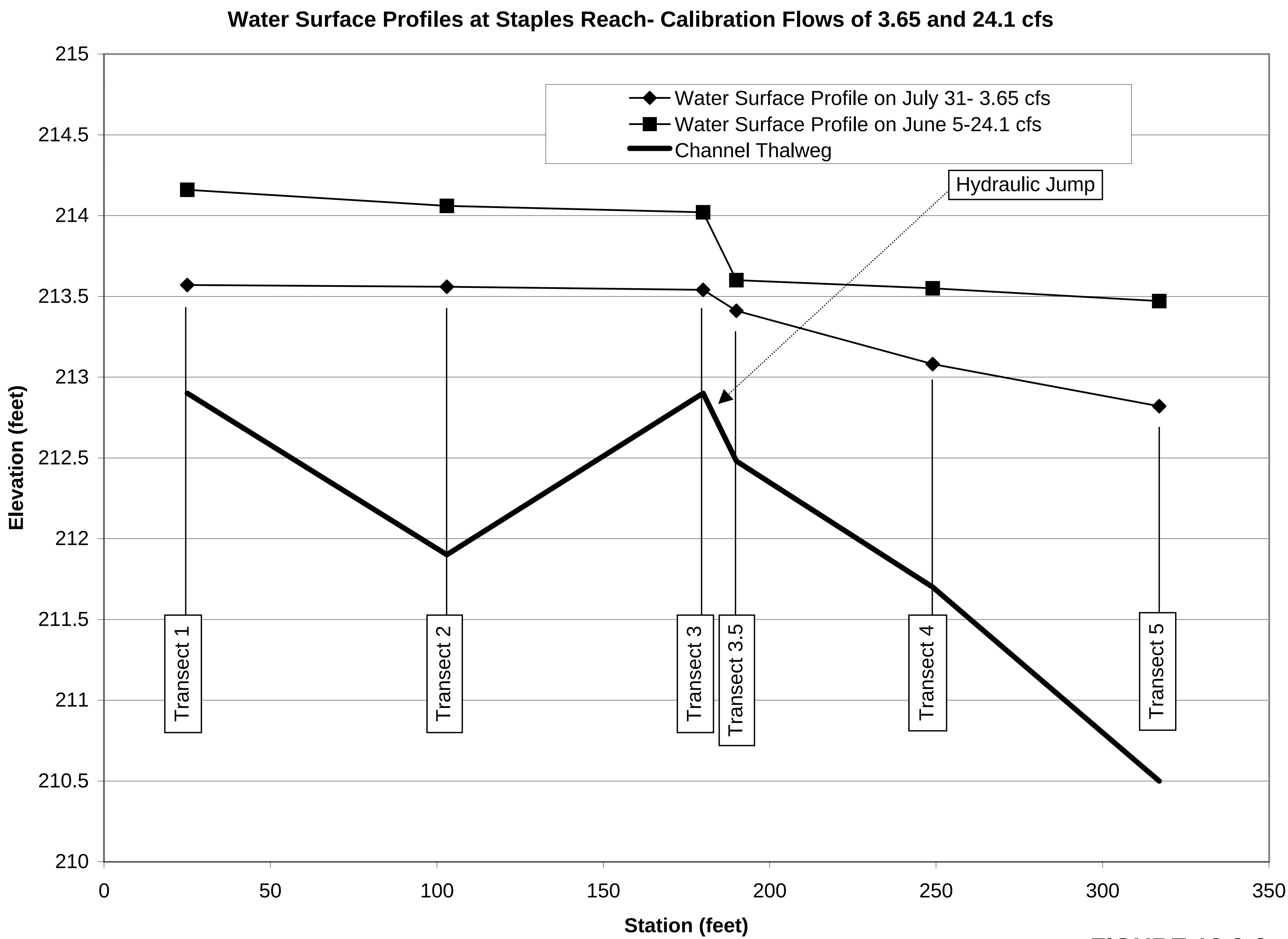


FIGURE 12.3–1
PLAN VIEW OF LOWER REACH
SHOWING TRANSECT LOCATIONS
SCALE 1" = 40'



Water Surface Profiles at Staples Reach- Calibration Flows of 3.65 and 24.1 cfs
Water Surface Profile on July 31- 3.65 cfs
Water Surface Profile on June 5-24.1 cfs
Channel Thalweg
Hydraulic Jump
Transect 1
Transect 2
Transect 3
Transect 3.5
Transect 4
Transect 5
Elevation (feet)
Station (feet)
215
214.5
214
213.5
213
212.5
212
211.5
211
210.5
210
0
50
100
150
200
250
300
350

FIGURE 12.3-2

13.0 Habitat Model

Once the hydraulic model is calibrated and predicts velocities and depths over a range of flows, it is then married with a habitat model. The amount of aquatic habitat for a given species/life stage of fish is calculated using the habitat program (the program is called HABTAE- this is not an acronym), which is part of the Physical Habitat Simulation Program (PHABSIM) library of computer programs developed by the USFWS for use in IFIM studies. The HABTAE program divides the stream into a series of rectangular cells. Each cell is evaluated for its habitat suitability for a particular species/life stage based on the fixed characteristics (such as substrate and cover) and the variable characteristics of the cell (such as depth and velocity).

Fish habitat, as used in IFIM procedures, is quantified in terms of a variable known as Weighted Usable Area (WUA). A unit of WUA represents a unit of optimum habitat for the life stage evaluated. The following equation is used to calculate WUA:

$$WUA = \frac{\sum_{I=1}^{n} WUA(I)}{L} \times L_{macro}$$

where: $WUA(I)$ = Weighted Usable Area in cell (I);
n = Total number of cells in the reach;
L = Total length of the study reach; and
L_{macro} = Length of stream, which is represented by the reach, with suitable macrohabitat conditions.

The individual cell WUA(I) is calculated as follows:

$$WUA(I) = CF(I) \times Area(I)$$

where: Area(I) = Surface area of cell(I); and
CF(I) = Compound Function Index for cell(I)

The Compound Function Index, CF(I), is calculated as follows:

$$CF(I) = SI_V \times SI_D \times SI_S$$

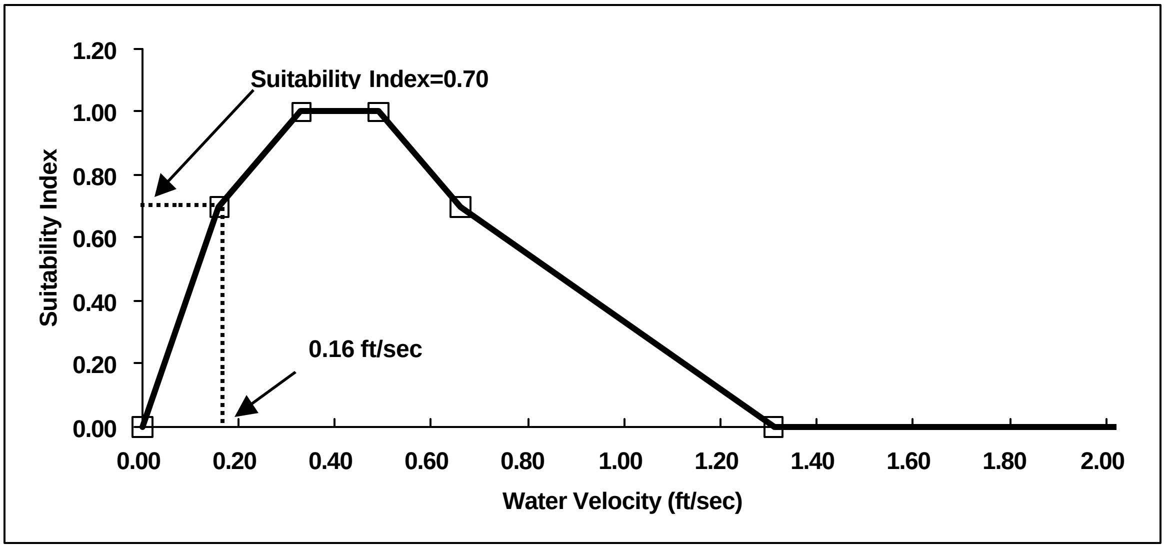
where: SI_V = Suitability Index for Velocity;
SI_D = Suitability Index for Depth; and
SI_S = Suitability Index for Substrate/Cover.

Although the above equations may appear complex, in reality, the formulas used to calculate WUA are rather straightforward. Examples of how these equations are used are provided so readers can better understand how aquatic habitat (or WUA) is calculated.

EXAMPLE CALCULATION:
Transect X, Data Collected in one of the "cells" of Transect X shows the following:

Velocity= 0.16 ft/sec, Depth= 1.4 feet, Substrate= Cobble, Highly Embedded, No Cover (Substrate Code of 7.93). Species of interest is Juvenile, White Sucker. The area of the cell is 0.5 feet wide by 50 feet long (this is the distance above and below Transect X that has similar substrate characteristics), thus the cell surface area is 25 sq ft.

The habitat model will first calculate the suitability index value for velocity, depth and substrate based on the field data collected for Transect X. Provided below is the velocity suitability index curve for adult white suckers. Based on cell velocity of 0.16 ft/sec, the corresponding suitability is 0.70 (thus SI_v= 0.70). Remember that a suitability value of 1.0 represents optimal habitat, and a suitability value of 0.0 represents no habitat.



The same process is conducted for depth and substrate. The model will use the given depth and substrate and produce a suitability index value for both depth and substrate based on the juvenile white sucker habitat suitability index curves. Following through with this example, the suitability index value corresponding to 1.4 feet in depth is 0.50 (SI_d=0.5). Juvenile white suckers prefer any substrates, thus the suitability index value corresponding to a substrate code of 7.93 is 1.0 (SI_s=1.0).

The Compound Function Index for this cell is then computed by the program as follows:

$CF(I) = SI_V \times SI_D \times SI_S = 0.70 \times 0.50 \times 1.0 = 0.35.$

The next step is to compute the weighted usable area (WUA) by multiplying the surface area (25 sq ft) of the cell by the Compound Function Index as follows:

WUA(I) = CF(cell) x Area(cell)= 0.35 x 25 sq ft= 8.75.

The WUA is then computed for each cell and summed for each transect. In a given study section or reach, the WUA(I) for all the cells are summed, divided by the study reach length, and expressed in units of square feet per 1,000 feet. This number is then multiplied by the total representative stream length with appropriate macrohabitat conditions to develop composite WUA versus flow curves. For example, two WUA versus flow curves will be developed- one for the Diversion Reach and the other for the Staples Reach (for each species/life stage). The WUA units are square feet per 1,000 feet of river. To compute the total habitat area, the length of stream representing the Diversion Dam and length of stream representing the Staples Reach would be multiplied by the WUA with the resulting units of square feet.

As noted in the habitat mapping section, the majority of the Saugus River is comprised of slow-moving runs with silt/sand substrate. In fact, 93% of the river surveyed from the Diversion Dam to the USGS gage was run habitat, followed by riffles (5.7%) and pools (1.3%). The two reaches (Diversion Dam and Staples) where habitat data was collected are not necessarily the same as the entire Saugus River. As noted earlier in this report, members of the team believed that any flow recommendation resulting from the study of these two reaches would represent the critical aquatic habitat that would control the balance of the Saugus River.

It should also be noted that typically the WUA results from both the Diversion Dam Reach and Staples Reach would be combined to produce one WUA versus flow curve. However, because the findings at each reach were quite different, they have been broken out separately. Described in the following section are the habitat results for the various species and life stages examined in this study.

14.0 Habitat Results

This section presents and explains the results of the HABTAE modeling in terms of WUA versus flow relationships for the two study reaches. In both reaches a high and low flow data set was collected. It is not uncommon for separate low and high flow hydraulic models of the same study reach, under the same or similar flows, to have differences in WUA values. This is because small differences in predicted depths and velocities from independently produced models can correspond to large differences in cellular SI values, particularly in those cases where the SI curves are steep. This phenomenon commonly occurs and no additional amount of field work can rectify it. The high and low flow modeling results were combined to produce one WUA versus flow relationship for each species and life stage of fish. Appendix M includes both the high and low flow WUA versus flow results and shows which values were selected for the analysis of each study reach.

The key to understanding the WUA versus flow relationships is to compare the hydraulic data for the various simulated flows (depth and velocity) to the habitat suitability index curves as discussed below. To help understand the results, the average depth and velocity of each transect (for the Diversion Dam Reach and Staples Reach) are shown in Tables 14.0-1 and 14.0-2. It should be clearly noted that these are average depths and velocities across a given transect. Obviously, the cellular depths and velocities will vary across the stream. These tables can be used as guide to interpret the WUA versus flow curves.

Table 14.0-1: Diversion Dam Reach- Average Depths and Velocities from Hydraulic Model

Average Depth Across Transect (in feet)												
	12 cfs	**14 cfs**	**16 cfs**	**18 cfs**	**20 cfs**	**24 cfs**	**28 cfs**	**30 cfs**	**40 cfs**	**50 cfs**	**60 cfs**	**70 cfs**
Transect 8	0.63	0.64	0.64	0.64	0.68	0.72	0.77	0.77	0.84	0.93	1.01	1.06
Transect 6	1.15	1.18	1.20	1.23	1.25	1.34	1.42	1.46	1.63	1.78	1.91	2.04
Transect 4	0.50	0.55	0.60	0.65	0.69	0.76	0.77	0.76	0.87	0.97	1.07	1.15
Transect 2	0.45	0.49	0.53	0.57	0.61	0.67	0.74	0.77	0.90	1.01	1.11	1.21
Transect 1	0.60	0.65	0.69	0.73	0.77	0.84	0.91	0.94	0.97	1.10	1.22	1.32
Average Velocity Across Transect (feet/second)												
Transect 8	1.66	1.85	2.02	2.15	2.26	2.54	2.75	2.95	3.50	3.89	4.23	4.63
Transect 6	0.73	0.82	0.90	0.98	1.05	1.19	1.32	1.39	1.68	1.95	2.19	2.41
Transect 4	1.94	2.04	2.14	2.22	2.30	2.46	2.60	2.67	2.96	3.20	3.41	3.58
Transect 2	1.62	1.72	1.82	1.90	1.98	2.12	2.24	2.29	2.53	2.72	2.89	3.03
Transect 1	1.34	1.42	1.50	1.57	1.63	1.75	1.86	1.91	2.13	2.31	2.47	2.61

Table 14.0-2: Staples Reach- Average Depths and Velocities from Hydraulic Model

Average Depth Across Transect (in feet)									
	10 cfs	**12 cfs**	**16 cfs**	**20 cfs**	**24.1 cfs**	**30 cfs**	**40 cfs**	**50 cfs**	**60 cfs**
Transect 5	0.28	0.32	0.37	0.43	0.43	0.47	0.53	0.60	0.66
Transect 4	0.45	0.46	0.54	0.64	0.66	0.77	0.88	0.97	1.04
Transect 2	1.27	1.30	1.35	1.41	1.46	1.52	1.60	1.67	1.72
Transect 1	0.92	0.96	1.02	1.09	1.15	1.24	1.33	1.42	1.48
Average Velocity Across Transect (feet/second)									
Transect 5	2.71	2.79	2.95	2.98	3.27	3.30	3.52	3.70	3.88
Transect 4	0.99	1.06	1.21	1.31	1.52	1.66	1.98	2.26	2.54
Transect 2	0.51	0.60	0.76	0.91	1.06	1.24	1.56	1.86	2.16
Transect 1	0.86	0.99	1.22	1.43	1.62	1.85	2.25	2.60	2.95

In the discussion below, we refer to the flow where the WUA versus flow curve peaks. For example, peak habitat for the spawning and incubation life stage of longnose dace occurs at a flow of 20 cfs in the Diversion Dam Reach. At a flow of 20 cfs, the computed habitat area over the length of the Diversion Dam Reach is 4,489 square feet. Assuming optimal habitat conditions were prevalent for the spawning and incubation life stage of longnose dace throughout the entire Diversion Dam Reach[28], the total habitat area would be 18,461 square feet at a flow of 20 cfs (obviously as the flow increases the total available habitat area increases as the river widens). Thus, although 20 cfs represents the flow at which the habitat peaks, it actually represents only 24% of the total potential habitat. Shown in Table 14.0-3 is a summary of the flow where the WUA curve peaks, the habitat area at maximum WUA flow, the total available habitat, and the percentage of total habitat available at the peak WUA.

The purpose for including this table is to put into perspective how much habitat is used for a given species/life stage in the Diversion Dam Reach and Staples Reach relative to the total amount of habitat. As the percentages in the far right-hand column show there is not a large quantity of habitat available for the various species and life stage examined in the two reaches. In particular, there is limited spawning and incubation habitat for most species. Readers should also recognize that the two study reaches consisted of several riffle reaches, where habitat conditions are typically more ideal for juvenile and adult fish, and macroinvertebrates. Again, the majority of the Saugus River is a slow moving deep run with silt/muck substrate, which provides limited habitat for most of the species and life stages examined in this study.

Table 14.0-3: Percent of Peak WUA relative to Total Habitat Available (Diversion Dam and Staples Reaches)

Species/Life Stage	Maximum WUA Flow (cfs)	Habitat Area at Maximum WUA Flow (ft^2)	Total Available Habitat (ft^2)	% of Total Habitat Available at the Peak WUA Col 3/Col 4 (%)
Diversion Dam Reach				
Longnose Dace:				
Spawning & Inc.	20	4,489	18,461	24%
Fry	20	7,429	18,461	40%
Juvenile	16	4,405	17,801	25%
Adult	20	5,397	18,461	29%
Fallfish:				
Spawning & Inc.	40	2,925	20,800	14%
Fry	16	8,228	17,801	46%
Juvenile	50	7,697	21,540	36%
Adult	70+	2,506	22,788	11%
Common Shiner:				
Spawning & Inc.	8.2	2,461	17,416	14%
Fry	60	1,683	22,226	8%
Juvenile	70+	1,647	22,788	7%

[28] This assumes that the composite suitability for each cell, for each transect within the entire length of the Diversion Dam Reach is equivalent to 1—in other words optimal habitat throughout the whole reach.

Species/Life Stage	Maximum WUA Flow (cfs)	Habitat Area at Maximum WUA Flow (ft^2)	Total Available Habitat (ft^2)	% of Total Habitat Available at the Peak WUA Col 3/Col 4 (%)
White Sucker:				
Spawning & Inc.	60	2,032	22,226	9%
Fry	70+	5,426	22,788	24%
Juvenile/Adult	70+	2,754	22,788	12%
Macroinvertebrate	70+	9,852	22,788	43%
Staples Reach				
Longnose Dace:				
Spawning & Inc.	24	803	23,821	3%
Fry	12	7,875	23,085	34%
Juvenile	10	916	22,171	4%
Adult	24	1,321	23,821	6%
Fallfish:				
Spawning & Inc.	30	2,128	24,312	9%
Fry	10	7,817	22,170	35%
Juvenile	30	11,897	24,312	49%
Adult	30	5,454	24,312	22%
Common Shiner:				
Spawning & Inc.	12	1,478	23,085	6%
Fry	40	550	24,653	2%
Juvenile	10	1,329	22,170	6%
White Sucker:				
Spawning & Inc.	24	1,932	23,821	8%
Fry	3.6	11,349	15,992	49%
Juvenile/Adult	12	4,594	23,085	18%
Macroinvertebrate	60+	11,361	25,188	45%

14.1 Diversion Dam Reach

14.1.1 Longnose Dace

Spawning and Incubation (S&I): Shown in Figure 14.1.1-1 is the WUA versus flow relationship for all life stages of longnose dace. The WUA graph for the spawning and incubation (S&I) life stage shows habitat increasing, reaching a peak around 20 cfs, and declining thereafter. The curve peaks around 20 cfs because the velocity in the Diversion Dam Reach at flows above 20 cfs start to exceed the optimal range (SI=1.0) of 1.25-2.25 ft/sec. Optimal depths for the S&I life stage are 0.75-1.15 feet (SI=1.0). Based on the hydraulic model, depths in this range are observed only at high flows- in the 30-70 cfs range.

Fry: The WUA curve for fry also peaks around 20 cfs. Fry prefer low velocities (0.5-1.25 feet/sec) and depths between 0.75-1.25 feet. Fry habitat is typically located on the stream margin, where velocities are lower. Fry habitat declines above 20 cfs primarily due to water velocities exceeding the optimal range. For example, average velocities at the transects in this reach under 30 cfs range from 1.39-2.95 ft/sec. It is interesting to note that the total amount of habitat for fry exceeds that for S&I, juveniles and adults. Fry have more habitat since they have a wider range of acceptable substrates ranging from silt to cobble. Alternatively, juveniles have no preference (SI=0) for silt substrates. Thus, even if the velocity and depth in a given cell were optimal for juveniles, if the substrate in the cell were silt, then the CF(i) = 0.

Juvenile: Similar to the S&I and fry life stages, habitat for juvenile longnose dace increases, reaches a peak around 16 cfs, and then declines thereafter. Optimal depths for juveniles are 0.75-1.15 feet, and optimal velocities are 0.75 to 1.50 feet/sec. At flows above 16 cfs, velocities in the reach start to exceed the optimal range for juveniles, which reduces the quantity of habitat at the high flows.

Adults: Adult longnose dace habitat increases, peaks at 20 cfs, and declines thereafter. Adults prefer slightly higher velocities and depths than juveniles.

14.1.2 Fallfish

Spawning and Incubation: Shown in Figure 14.1.2-1 is the WUA curve for the various life stages of fallfish. The fallfish S&I curve gradually increases, and slowly peaks around 40 cfs, before slightly declining. The quantity of habitat does not change considerably over the range of flows between 20 to 70 cfs. The S&I life stage has optimal velocities between 1 and 1.5 feet/sec (SI=1.0) and the SI drops to 0.20 at 2.5 ft/sec. In this reach velocities exceed 1.5 ft/sec at flows as low as 12 cfs. The reduction in habitat (WUA) above 40 cfs is due to the velocity suitability index curve between 1.5 ft/sec (SI=1.0) and 2.5 ft/sec (SI=0.20). At flows in excess of 40 cfs, velocities are closer to 2.5 ft/sec. It should be noted that fallfish spawn on small gravel substrates. Thus, if a given cell contained optimal depth and velocity conditions, but the substrate was sand (which has a SI=0), the composite suitability would be zero.

Fry: Fry habitat increases, reaches a peak at 16 cfs, and then starts to decline. Fry have low velocity tolerances (SI= 0 at 2.9 feet/sec) and prefer water depths in the 0.25-1.65 feet range. Above 16 cfs, velocities become too excessive and thus the habitat starts to decline as evidenced in the WUA versus flow curve.

To illustrate the location of habitat at a given transect, color-coded habitat maps for fallfish fry are shown in Figures 14.1.2-2 and 14.1.2-3 under flows of 16 cfs (peak habitat) and 70 cfs (lowest habitat), respectively for the simulation at the Diversion Dam Reach. In this scenario, Transect 6 is shown along with the composite suitability values (Compound Function Index CF(i) as described above), which are color coded. The composite suitability is broken down as follows:

CF(i): 0 (black)
CF(i): 0.0-0.2 (red)
CF(i): 0.2-0.4 (yellow)
CF(i): 0.4-0.6 (green) poor to optimal habitat (optimal being CF(i)=1.0)
CF(i): 0.6-0.8 (light blue)
CF(i): 0.8-1.0 (blue)

As Figure 14.1.2-2 (16 cfs), illustrates most of the fry habitat is located along the margin of Transect 6 as velocities are lower (most of the habitat is colored blue). Most of the habitat in the middle of the stream has an SI of 0.0-0.2 (red) or 0.2-0.4 (yellow) because velocities are too high. Comparing this figure to Figure 14.1.2-3 (70 cfs), the amount of excellent habitat (0.8-1.0) is reduced and habitat in the middle of the stream is completely unusable (black). This is just one example of the color habitat maps that can be generated for a given transect, flow, species and life stage. The maps are used to understand the amount, quality and distribution of habitat.

A plan view of the composite suitability can also be developed as shown in Figures 14.1.2-4 (28 cfs plot) and 14.1.2-5 (70 cfs plot). The plan maps use the same color-coding scheme as the cross-section plots. Shown on the figures are the transect numbers (8, 6, 4, 2 and 1). Similar to the cross-section plots, the majority of habitat is located along the stream margin and decreases closer to center of the stream.

Juvenile: Juvenile habitat steadily increases with increasing flow, and plateaus around 50 cfs, before slowly declining. Optimal velocities for juveniles are 0.6-1.6 ft/sec (SI=1.0) and decreases to 2.0 ft/sec (SI=0.40). Optimal depths are 1-3 feet, which are not exceeded in this reach. The WUA curve starts to decline when river velocities start to exceed 2.0 ft/sec, which occurs around 50 cfs.

Adult: Adult habitat rises consistently with increasing flow, and never reaches a peak. Optimal velocities are between 0.1-0.8 ft/sec (SI=1.0) and drops to 3.0 ft/sec with a SI=0.0. In addition, all water depths greater than 3.0 have a SI=1.0.

14.1.3 Common Shiner

Spawning and Incubation: Shown in Figure 14.1.3-1 is the WUA curve for all life stages (except adults) of common shiner. For the S&I life stage, the WUA curve rises quickly, peaks around 8 cfs, and then sharply declines. Habitat peaks at a low flow because the S&I life stage has low velocity and depth tolerances (optimal depth – 0.49 feet, optimal velocity- 0.82 ft/sec). Flows in excess of 8 cfs have higher velocities and depths, which result in reducing the quantity of habitat.

Fry: Fry habitat rises over the range of flows modeled, until reaching a peak at 60 cfs. The quantity of habitat rises because water depths in the reach rarely exceed the optimal depth of 1.15 feet. At 70 cfs, the average depths start to exceed 1.15 feet and thus the WUA starts to decline.

Juvenile: The WUA curve for juveniles continually rises and never reaches a peak. At the highest modeled flow, 70 cfs, transect average depths range from 1.06-2.04 feet, while average velocities range from 2.41-4.63 ft/sec. The optimal water velocity for juveniles is 0.49 ft/sec (SI=1.0) and gradually declines to 1.80 ft/sec (SI=0.06). Alternatively, optimal depth is 1.80 feet, and declines to 2.46 feet (SI=0.11). The WUA curve never peaks because water depths rarely exceed the optimal depth of 1.80 feet.

14.1.4 White Sucker

Spawning and Incubation: Shown in Figure 14.1.4-1 is the WUA curve for all life stages of white sucker. The WUA curve rises slowly and finally peaks around 60 cfs. The WUA curve above 60 cfs drops because water velocities and depths become too excessive.

Fry: Fry habitat is highest at 4 cfs, then drops quickly before slowly increasing. Optimal velocities for fry are 0.0-0.3 ft/sec (SI=1) and drop to a suitability of 0 at 1 ft/sec. Optimal depths are greater than 1.0 foot (SI=1). At 4 cfs, water velocities are within the range 0.3 to 1.0 ft/sec range, however the suitability drops rapidly at higher flows. Interestingly, the habitat continues to slowly rise at the higher flows. The reason for this rise is the wetted area of the stream becomes larger and there is more cells along the stream margin that contain velocities in the optimal range. Effectively the WUA curve would continue to rise beyond the highest flow (70 cfs) if the area of habitat along the stream margin would increase.

Juvenile and Adult: The WUA curve declines below 4 cfs and then continually rises. Optimal velocity is between 0.33 and 0.49 ft/sec (SI=1) and drops to 1.31 ft/sec (SI=0). Alternatively, optimal depth is between 2.2 to 3.3 feet (SI=1), which rarely occurs in this reach due to the steep slope and water velocity. The WUA curve rises because more edge cells contain acceptable velocities as the flow increases. To illustrate, shown in Figures 14.1.4-2 and 14.1.4-3 are plan maps showing the composite suitability for juvenile white sucker under flows of 28 and 70 cfs, respectively at the Diversion Dam Reach. A comparison of these maps shows that more habitat becomes usable along the stream margin as flows increase.

14.1.5 Macroinvertebrates

Shown in Figure 14.1.5-1 is the WUA curve for macroinvertebrates, which rises sharply below 10 cfs and continually rises over the range of flows. Macroinvertebrates prefer velocities between 1-2.46 ft/sec (SI=1) and depths ranging from 0.4-3.0 ft (SI=1). Macroinvertebrates are most productive in fast moving riffle habitat. Overall, the total length of riffle reaches in the Saugus River (from the Diversion Dam to the USGS gage) represents roughly 1,529 feet, or 5.7% of the total stream length. Because fish feed on macroinvertebrates the amount of food production in the Saugus River is somewhat limited by the amount of riffle habitat and the flow rate over this habitat.

14.2 Staples Reach

14.2.1 Longnose Dace

Spawning and Incubation: Shown in Figure 14.2.1-1 are the WUA curves for all life stages of longnose dace. The WUA in the Staples Reach is generally low for this species. The S&I WUA curve does not vary significantly over the range of flows, primarily because this life stage has a wide range of acceptable depths and velocities.

Fry: Fry habitat increases quickly, peaks around 12 cfs, and declines thereafter. Again, water velocities in this reach start to exceed the optimal range of 0.5-1.25 ft/sec around 12 cfs.

Juvenile: The juvenile WUA curve is rather flat over the range of flows, but has a slight peak around 10 cfs.

Adult: The adult WUA curve is similar to the juvenile curve in that habitat does not vary considerably over the range of flows. There is a slight peak observed at approximately 24 cfs.

14.2.2 Fallfish

Spawning and Incubation: Shown in Figure 14.2.2-1 is the WUA curve for the various life stages of fallfish. The WUA curve remains relatively flat over the range of flows for the S&I life stage (there is a minor peak at 30 cfs). At 30 cfs, velocities start to exceed the optimal range of 1-1.5 ft/sec. It should also be noted that the only substrate used by spawners is small gravel (<2"). Thus, if the substrate was silt, gravel (2-4"), cobble or any other size substrate, the suitability is 0. In the Staples Reach, there were only a few locations where small gravel was present (in most of the river, the substrate is silty and would be unsuitable for this species/life stage.)

Fry: The WUA rises quickly, peaks around 10 cfs, and then drops thereafter. Above 10 cfs, velocities start to exceed the acceptable range for fry, which drives the WUA down.

Juvenile: The WUA for juveniles gradually increases, peaks at 30 cfs, and then declines. Juveniles have higher tolerances for high velocities (0.6-1.6 ft/sec, SI=1, 2.00 ft/sec, SI=0.4). The average velocities at transects 5, 4, 2, and 1 are 3.3, 1.7, 1.2, and 1.9 ft/sec, respectively under a flow of 30 cfs. Because the velocities are approaching 2.0 ft/sec, the WUA starts to decline above 30 cfs.

Adult: The WUA for adults gradually increases and reaches a peak around 30 cfs. Overall, the quantity of habitat does not vary considerably over the range of flows.

14.2.3 Common Shiner

Spawning and Incubation: Shown in Figure 14.2.3-1 is the WUA curve for all life stages (no adults were evaluated) of common shiner. Overall, the quality of suitable habitat (WUA) for this species is low. The WUA curve for S&I rises quickly, peaks at 12 cfs, and declines sharply thereafter. The sharp rise and decline is a function of the depth and velocity suitability index curves. Optimal velocity is 0.82 ft/sec (SI=1), but drops to a SI of 0.11 at 1.48 ft/sec. Similarly, optimal depth is 0.49 ft (SI=1), and declines quickly to 1.15 ft (SI=0.23). Water depths and velocities exceed the optimal range above 12 cfs, hence the WUA curve declines.

Fry: The WUA curve for fry continually increases, with two minor peaks at 20 and 40 cfs. The WUA gradually increases as the channel width widens and more habitat is gained along the stream margin. To illustrate, shown in Figures 14.2.3-2 and 14.2.3-3 are plan maps showing the composite suitability for common shiner fry at the Staples Reach under flows of 4 and 40 cfs, respectively. As the maps depict, the quality of habitat along the stream margin is better under 40 cfs versus 4 cfs, although the total amount of habitat does not vary considerably (and overall the amount of habitat under either flow is low and poor quality).

Juvenile: Habitat for juvenile shiners peaks around 10 cfs and gradually drops before reaching a second peak around 30 cfs. Habitat drops below 10 cfs as velocities start to exceed optimal (SI=1, V=0.49 ft/sec).

14.2.4 White Sucker

Spawning and Incubation: Shown in Figure 14.2.4-1 is the WUA curve for all life stages of white sucker. The S&I WUA curve rises and shows a slight peak around 24 cfs. In general, the amount of habitat does not vary considerably over the range of flows.

Fry: Fry habitat declines from the lowest flow simulated (3.65 cfs). The decline in habitat above 3.65 cfs is due to velocities exceeding the optimal of 0.30 ft/sec.

Juvenile and Adult: The WUA curve peaks around 12 cfs, and declines thereafter.

14.2.5 Macroinvertebrates

Macroinvertebrate habitat never peaks due to their preferences for high depth and velocity as shown in Figure 14.2.5-1. There is a steep increase in WUA with increasing flows up to about 20 cfs. Above 20 cfs, WUA does not increase significantly with increasing flow.

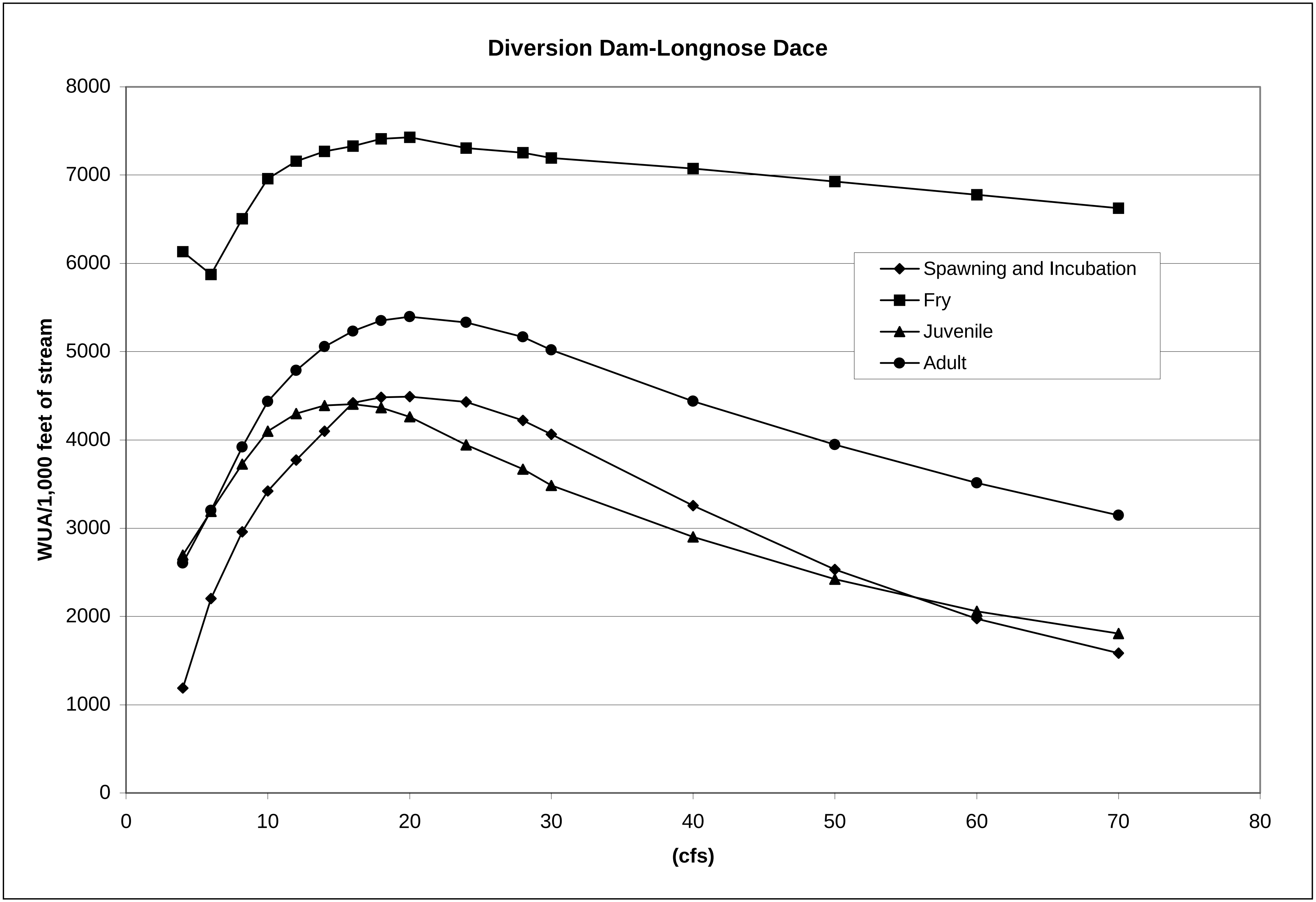


Figure 14.1.1-1: Diversion Dam Reach, Longnose Dace, WUA versus flow curve

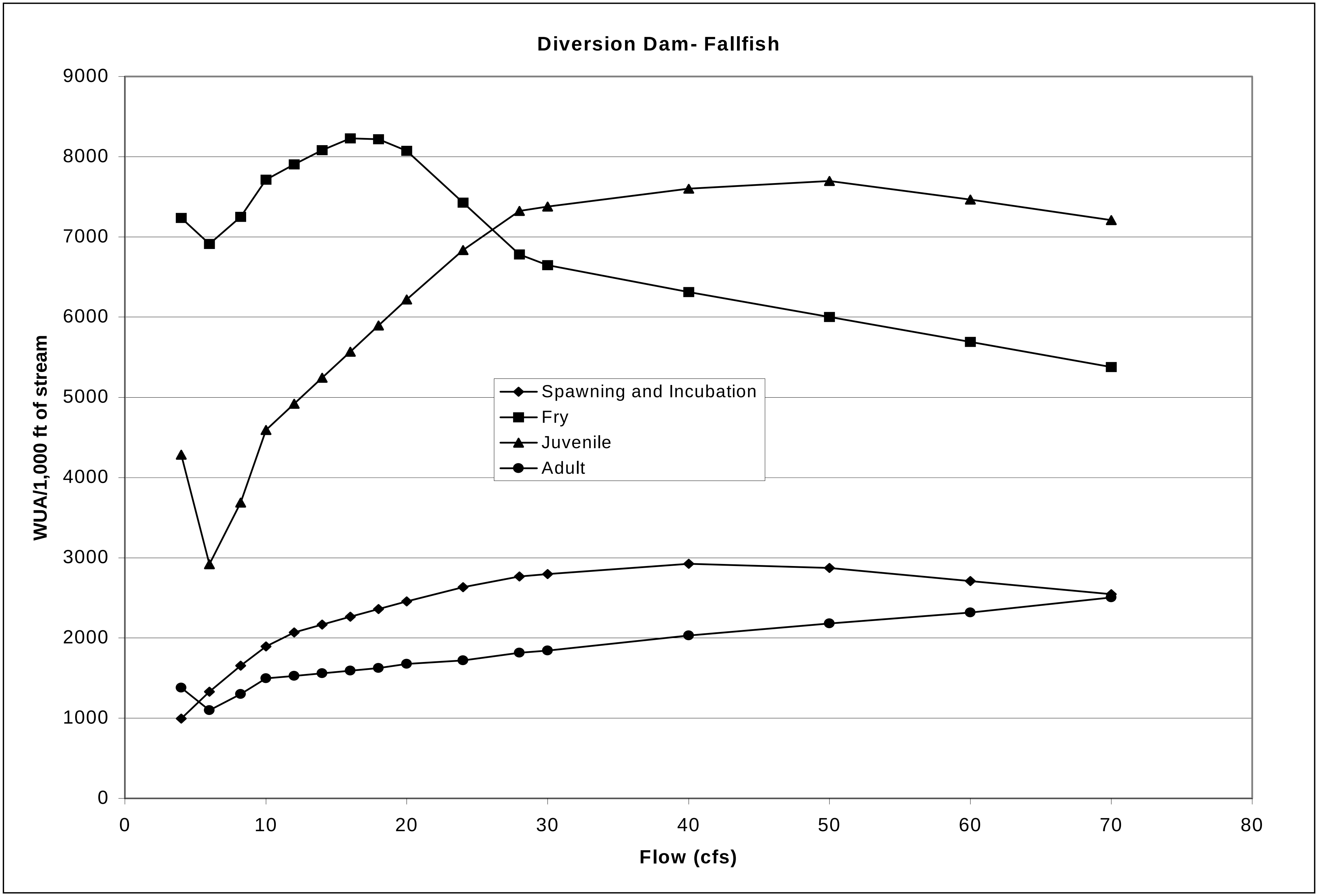


Figure 14.1.2-1: Diversion Dam Reach, Fallfish, WUA versus flow curve

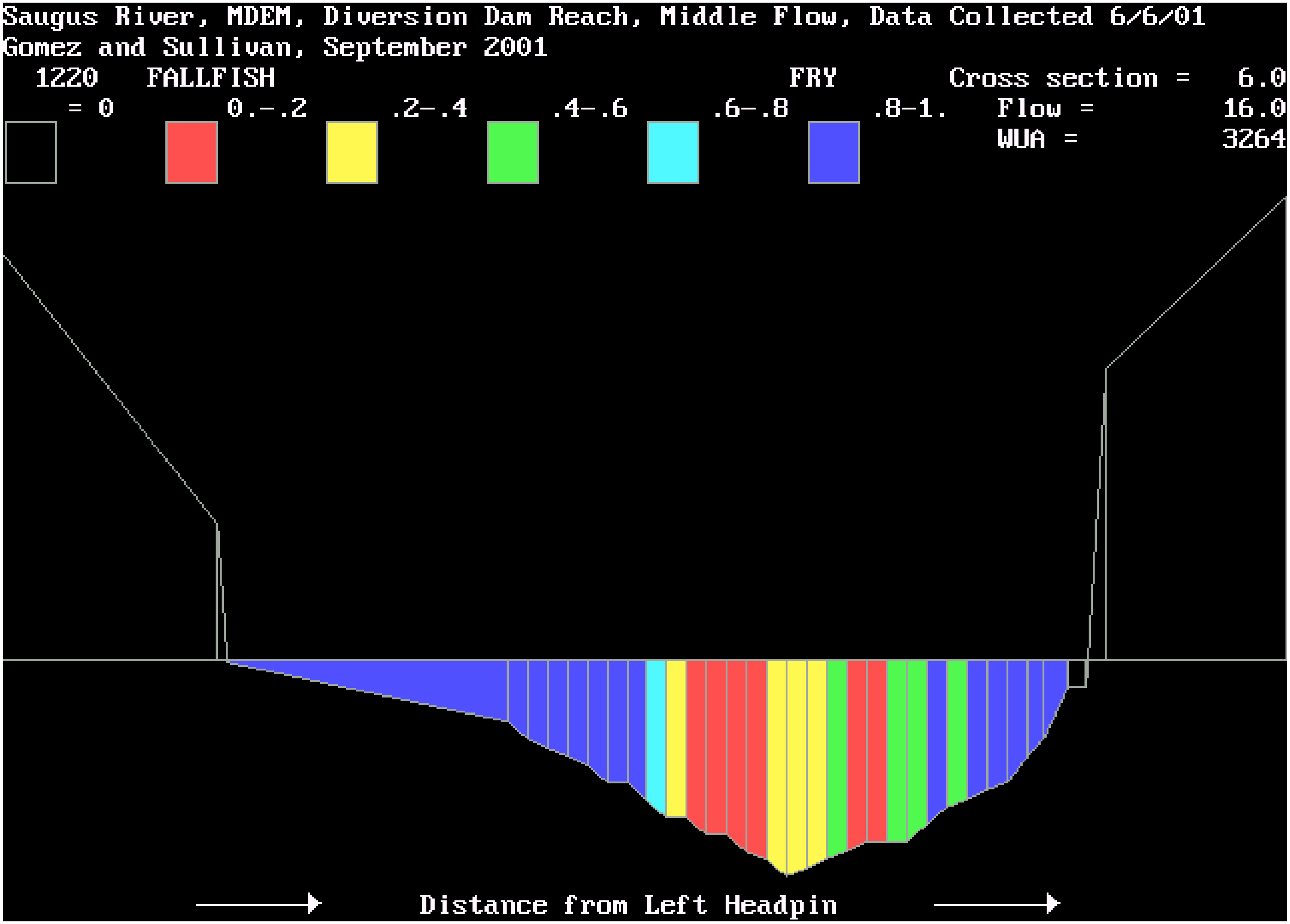


Figure 14.1.2-2: Diversion Dam Reach, Transect 6, Composite Suitability Index Values, Fallfish, Fry, *Flow=16 cfs*

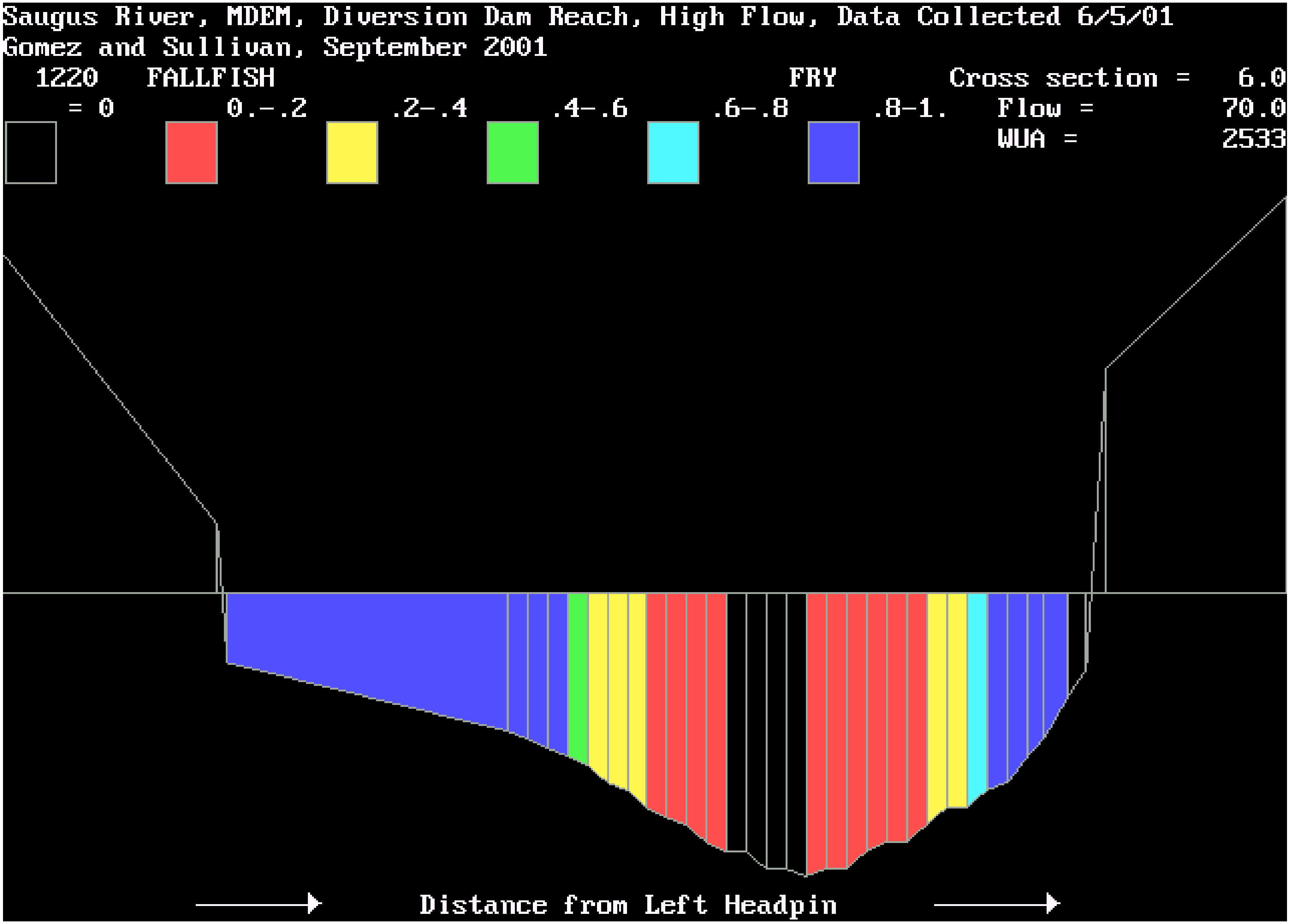


Figure 14.1.2-3: Diversion Dam Reach, Transect 6, Composite Suitability Index Values, Fallfish, Fry, *Flow=70 cfs*

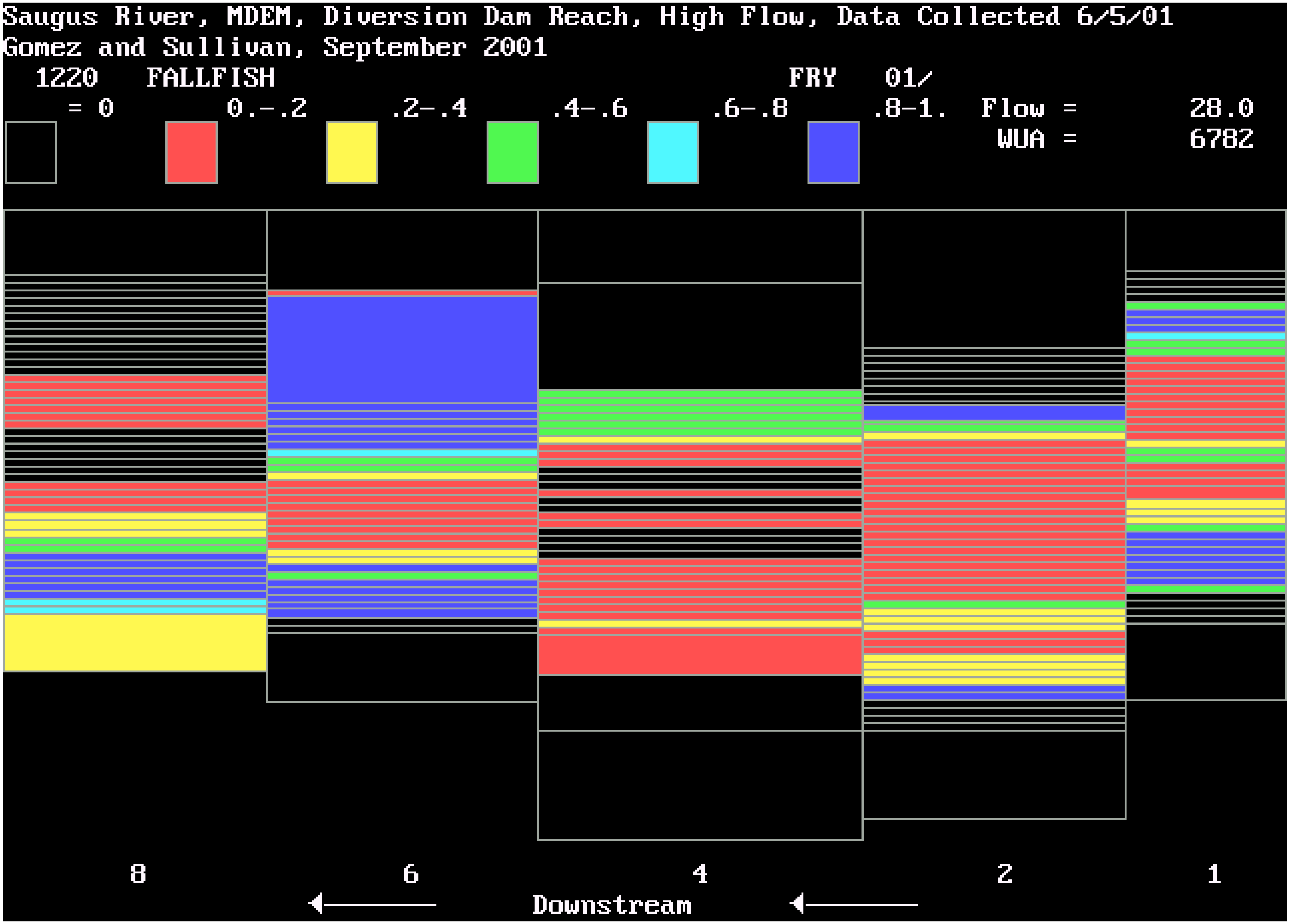


Figure 14.1.2-4: Diversion Dam Reach, Plan Map, Composite Suitability Index Values, Fallfish, Fry, *Flow=28 cfs*

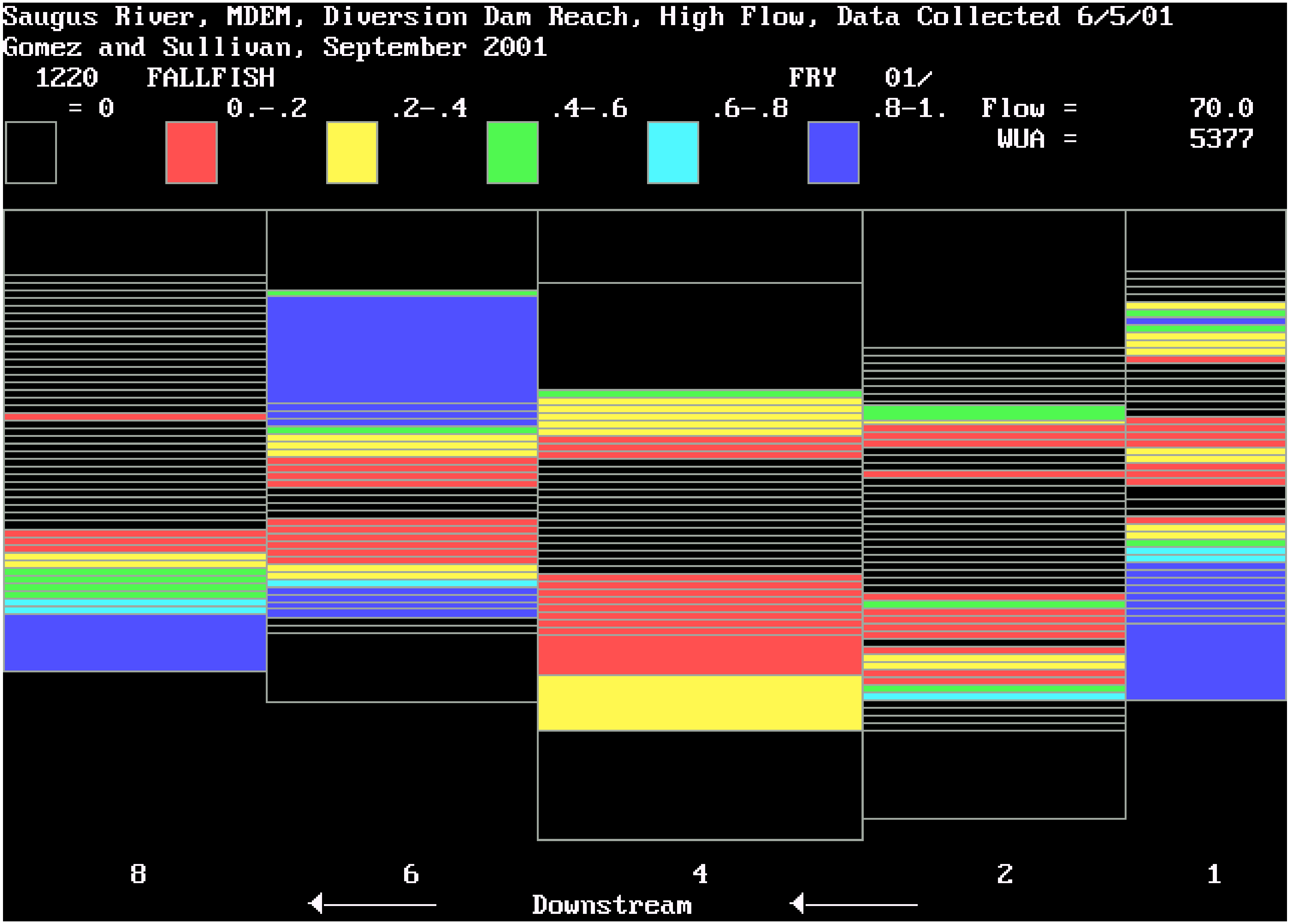


Figure 14.1.2-5: Diversion Dam Reach, Plan Map, Composite Suitability Index Values, Fallfish, Fry, *Flow=70 cfs*

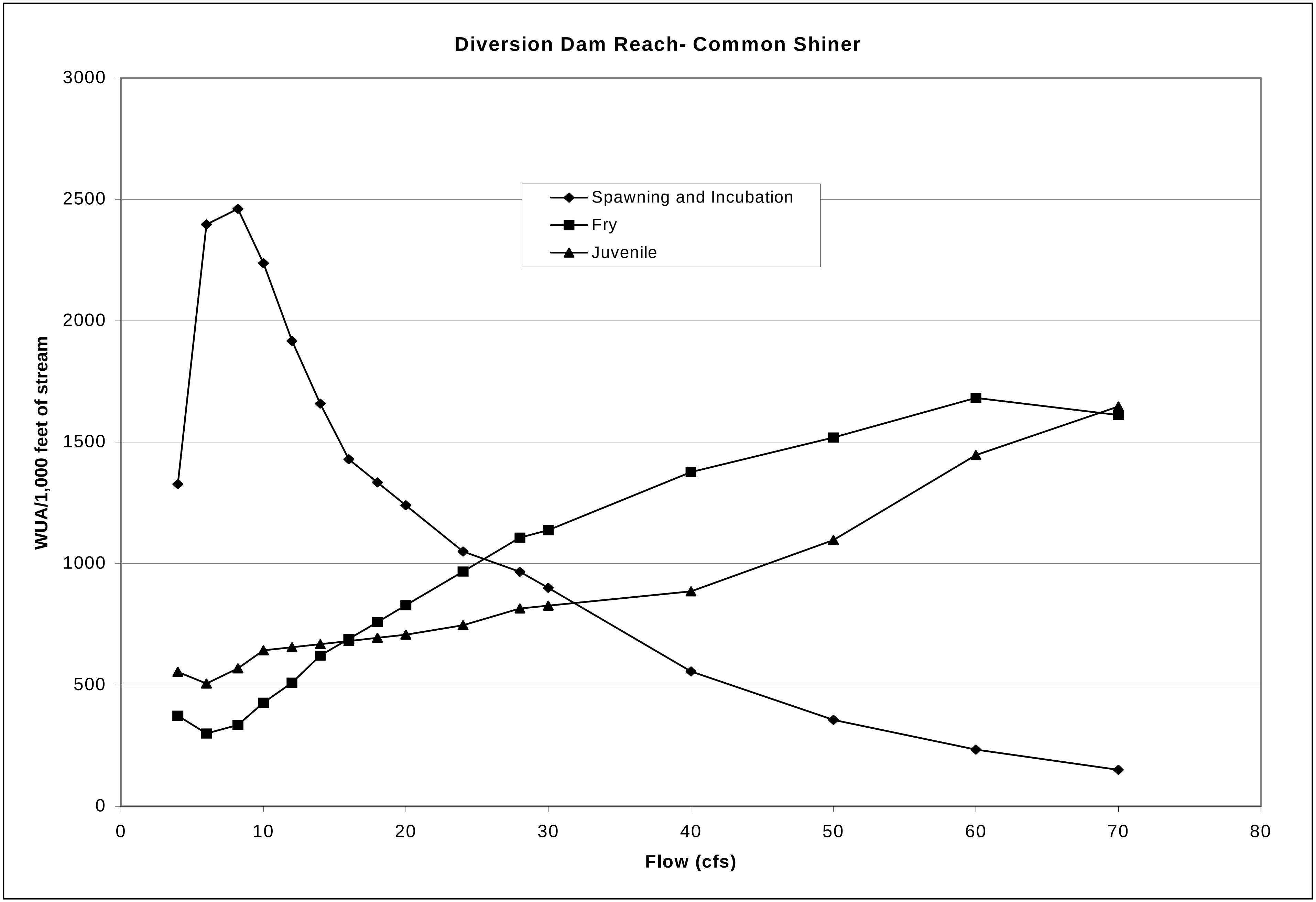


Figure 14.1.3-1: Diversion Dam Reach, Common Shiner, WUA versus flow curve

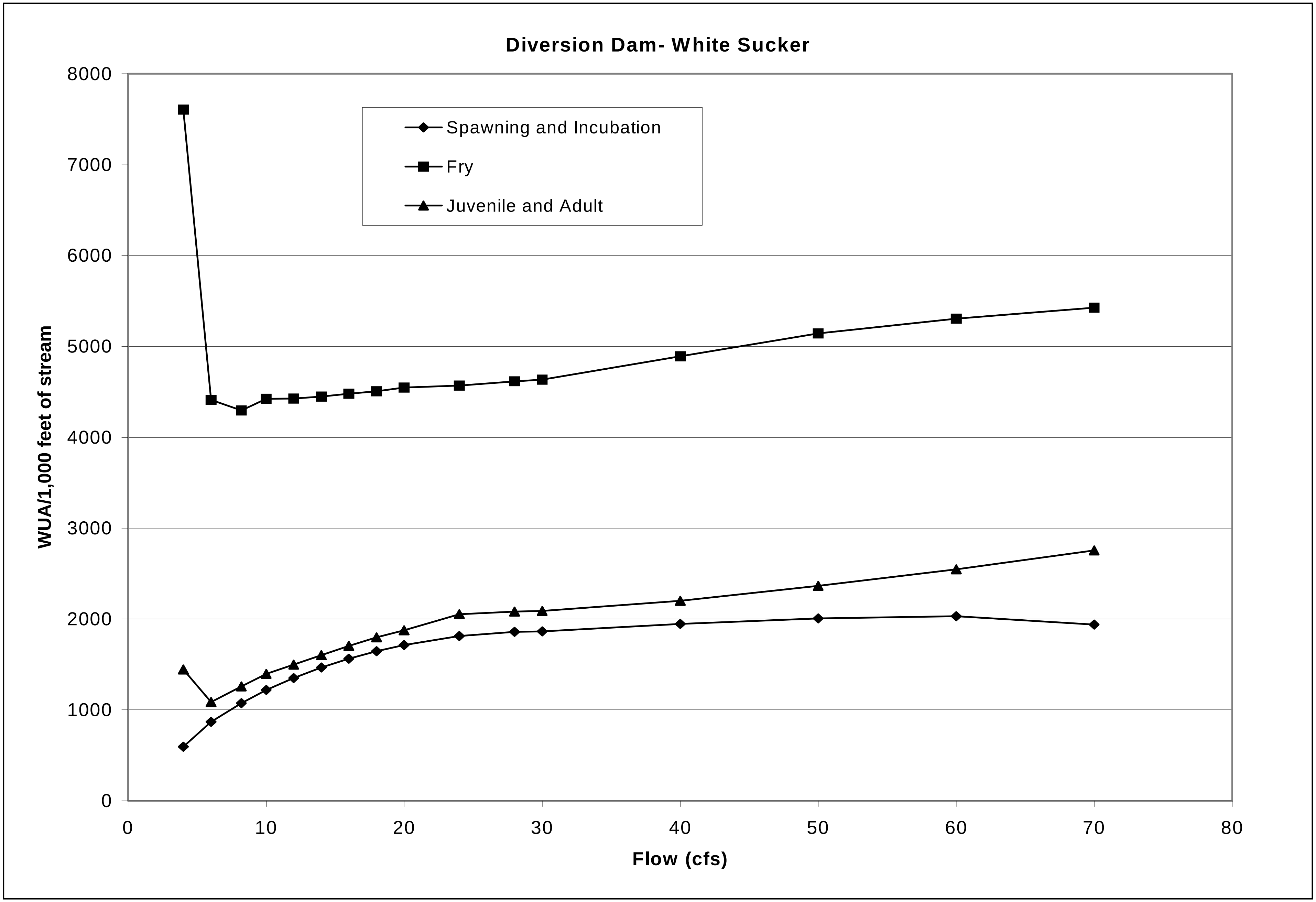


Figure 14.1.4-1: Diversion Dam Reach, White Sucker, WUA versus flow curve

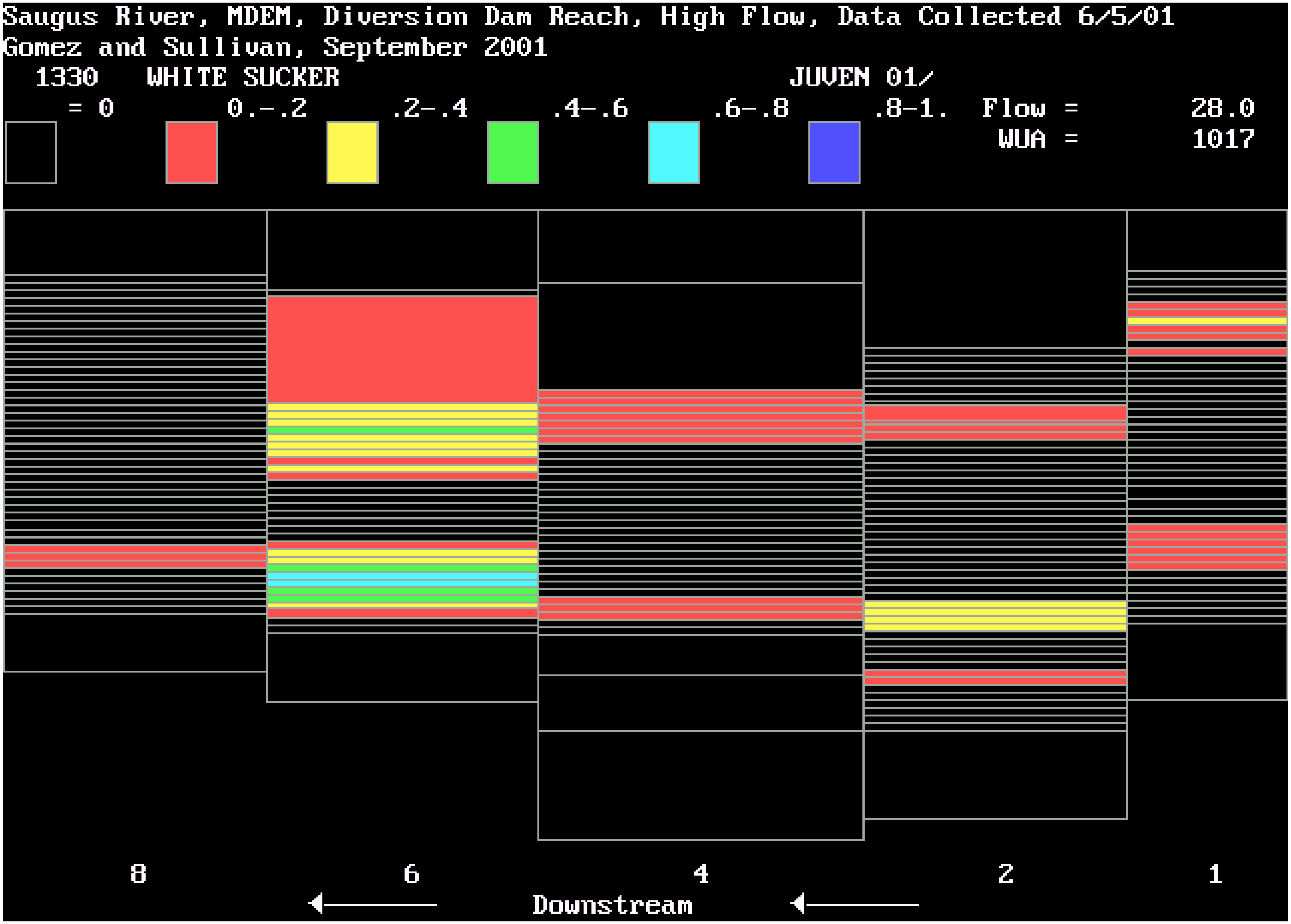


Figure 14.1.4-2: Diversion Dam Reach, Plan Map, Composite Suitability Index Values, White Sucker, Juvenile, *Flow= 28 cfs*

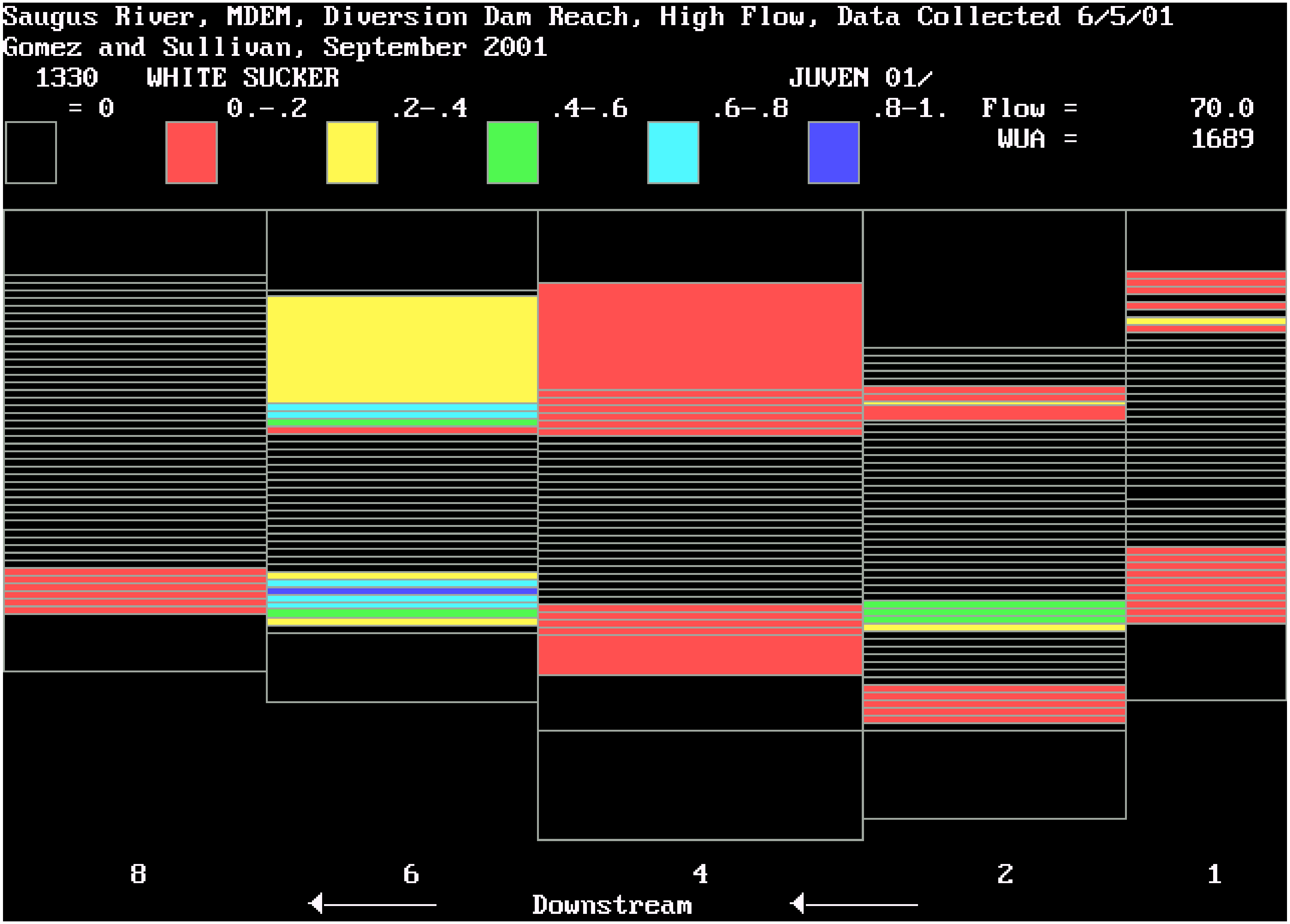


Figure 14.1.4-3: Diversion Dam Reach, Plan Map, Composite Suitability Index Values, White Sucker, Juvenile, *Flow= 70 cfs*

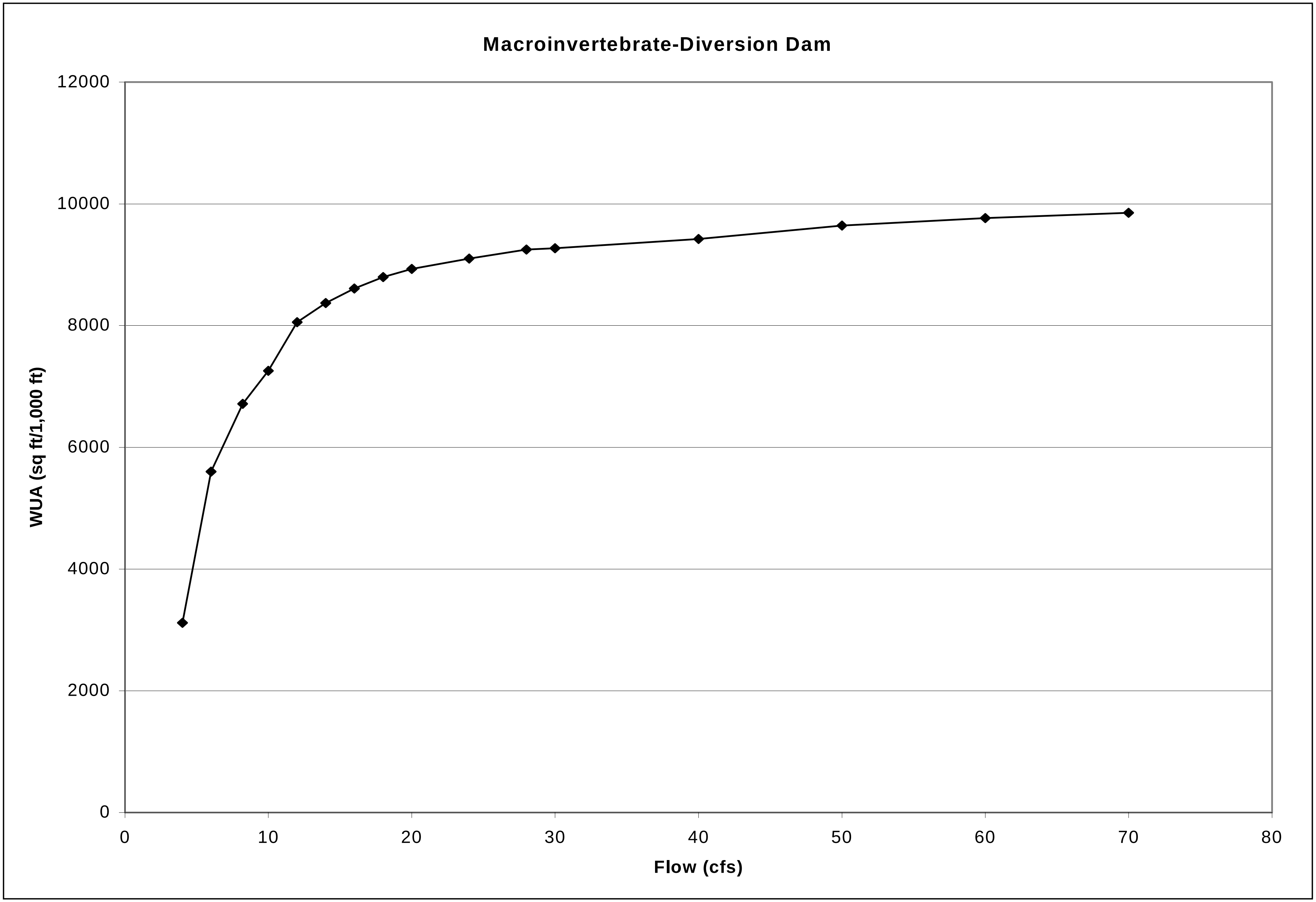


Figure 14.1.5-1: Diversion Dam Reach, Macroinvertebrate, WUA versus flow curve

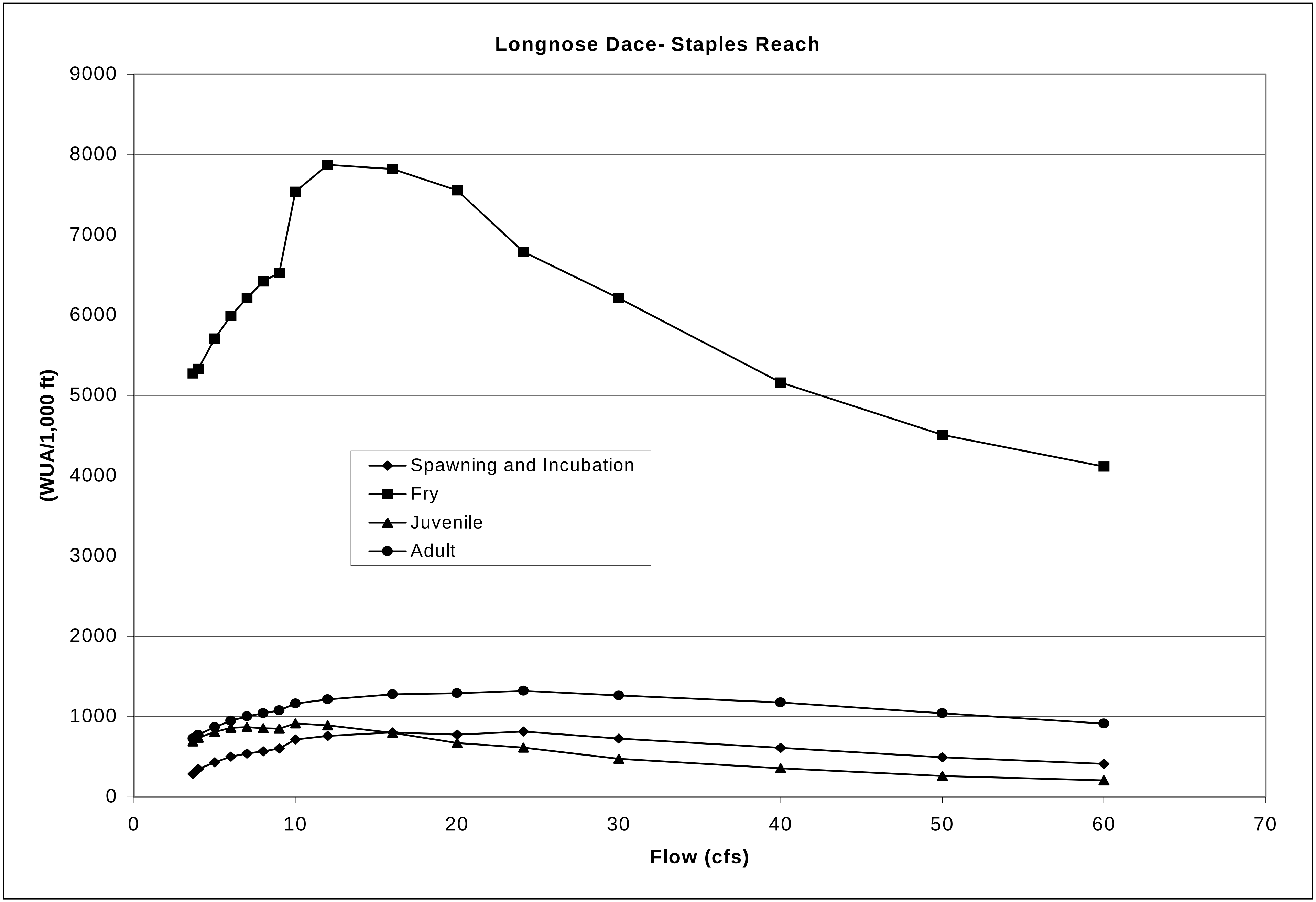


Figure 14.2.1-1: Staples Reach, Longnose Dace, WUA versus Flow Curve

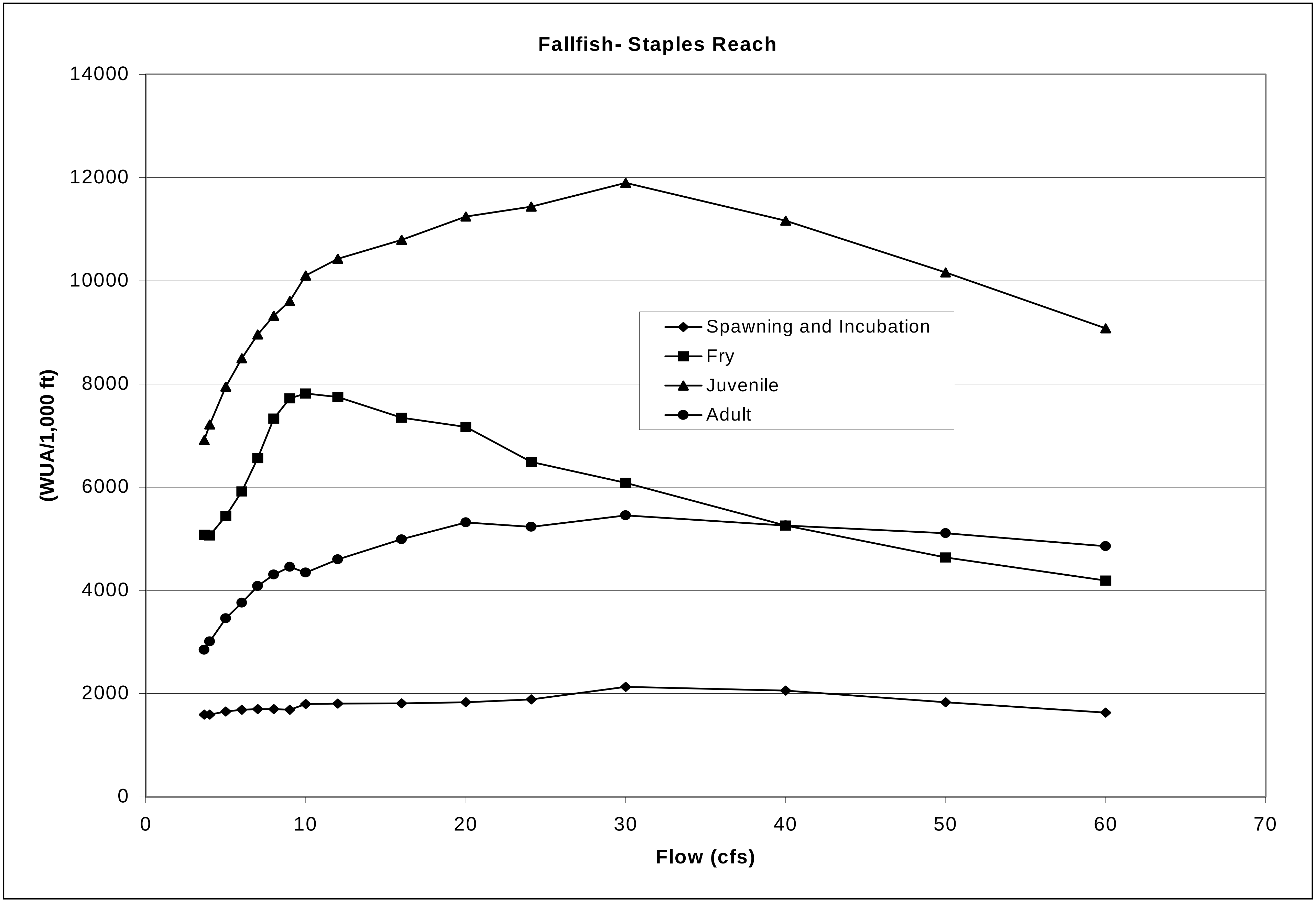


Figure 14.2.2-1: Staples Reach, Fallfish, WUA versus Flow Curve

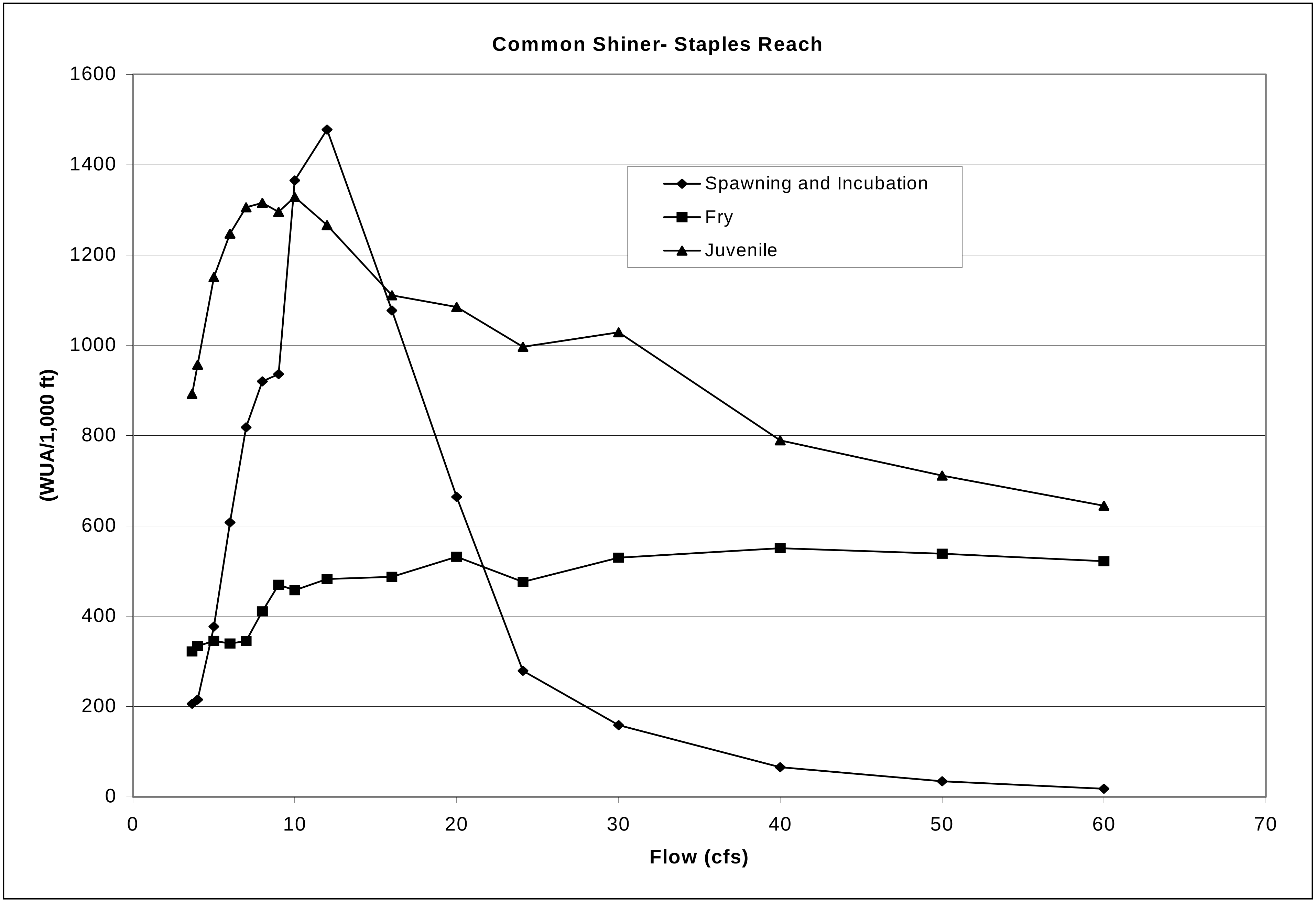


Figure 14.2.3-1: Staples Reach, Common Shiner, WUA versus Flow Curve

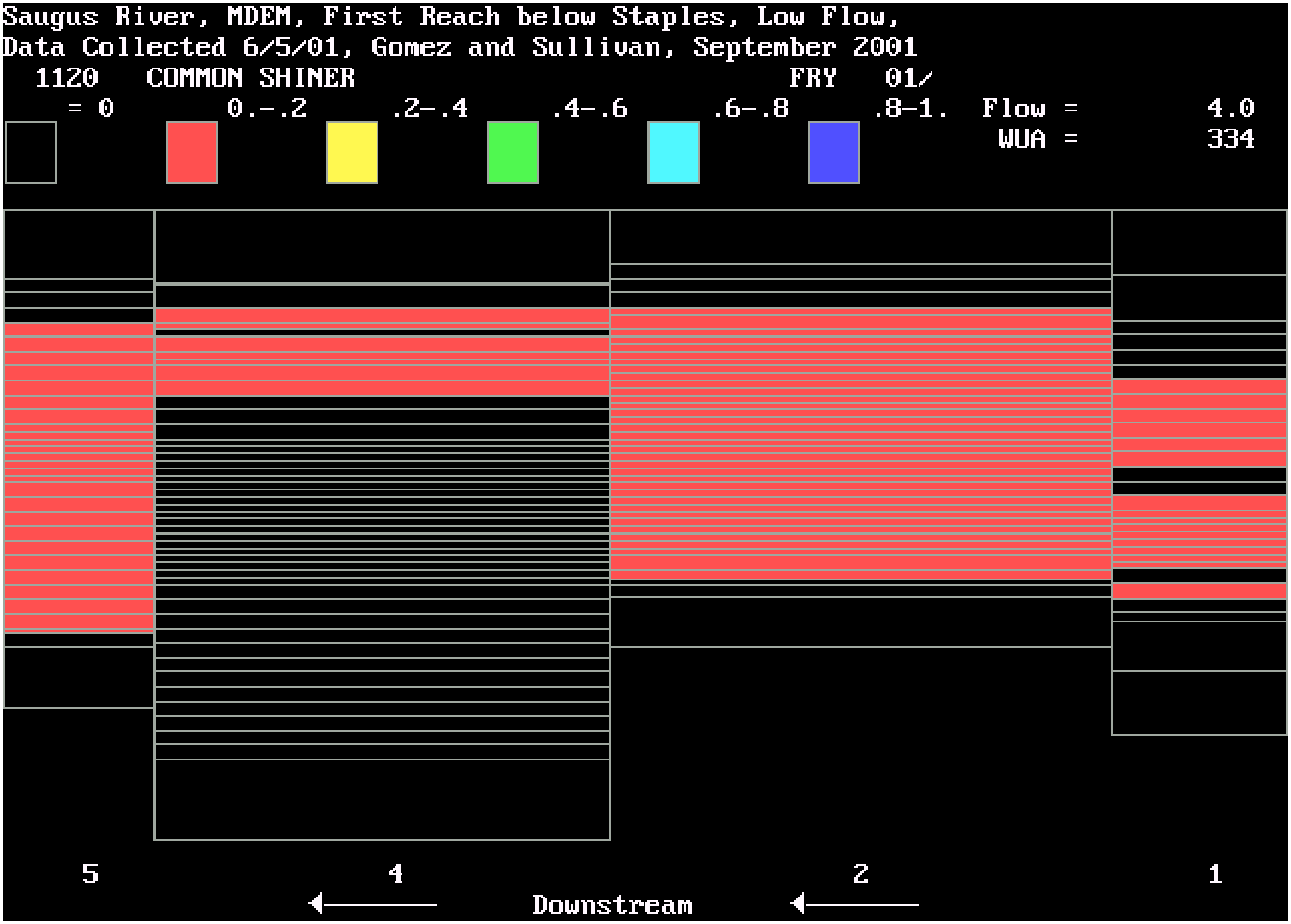


Figure 14.2.3-2: Staples Reach, Plan Map, Composite Suitability Index Values, Common Shiner, Fry, *Flow=4 cfs*

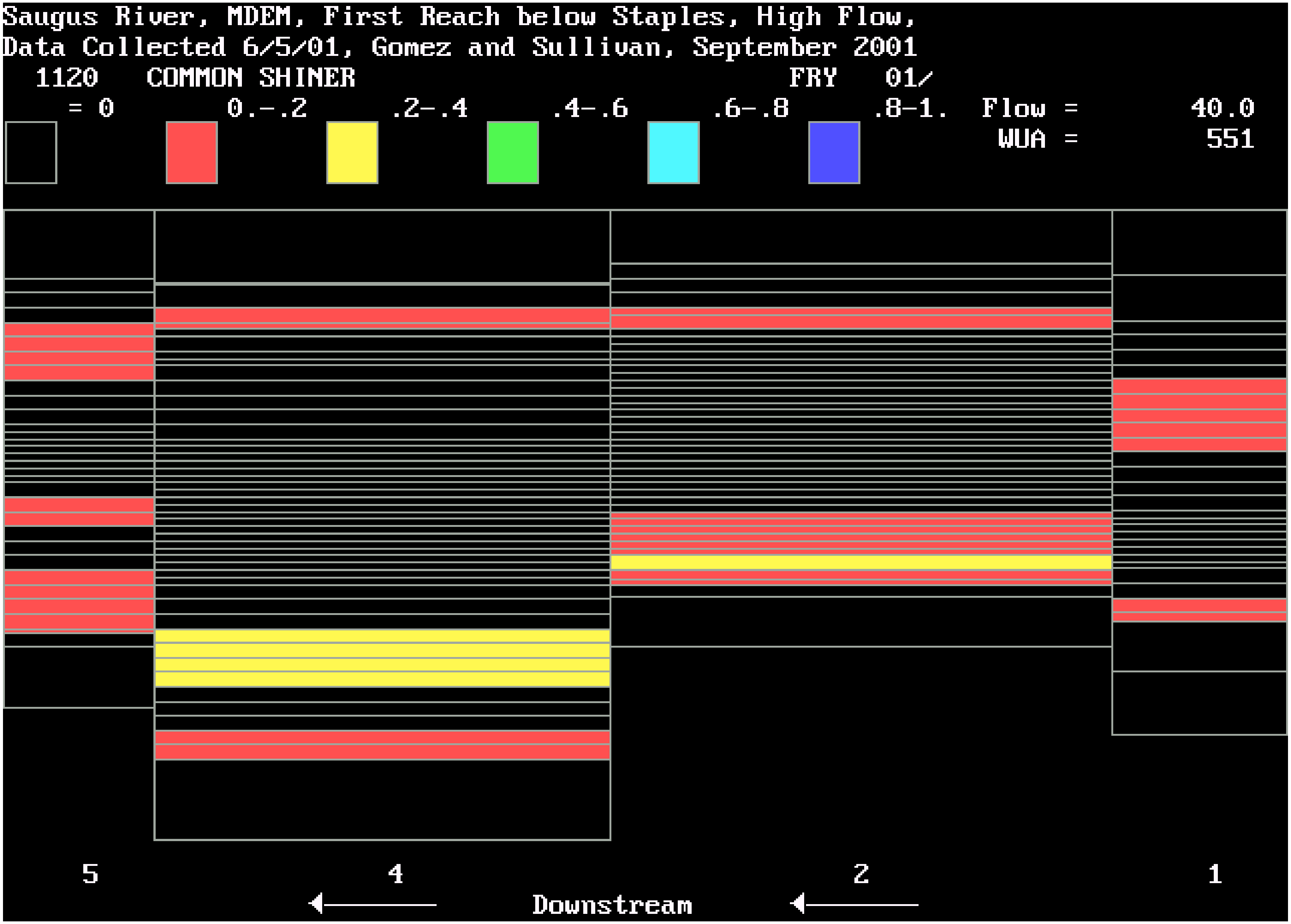


Figure 14.2.3-3: Staples Reach, Plan Map, Composite Suitability Index Values, Common Shiner, Fry, *Flow=40 cfs*

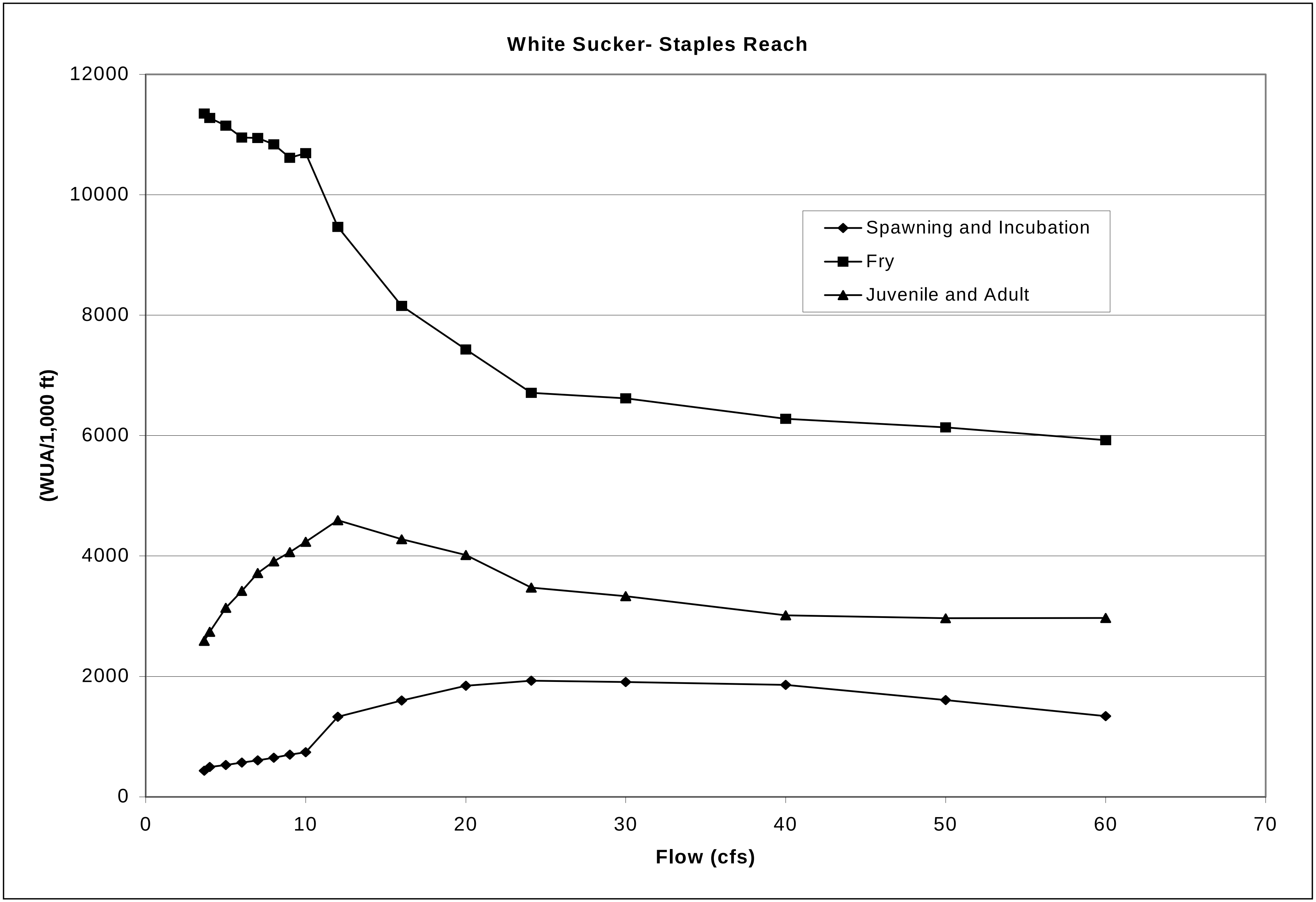


Figure 14.2.4-1: Staples Reach, White Sucker, WUA versus Flow Curve

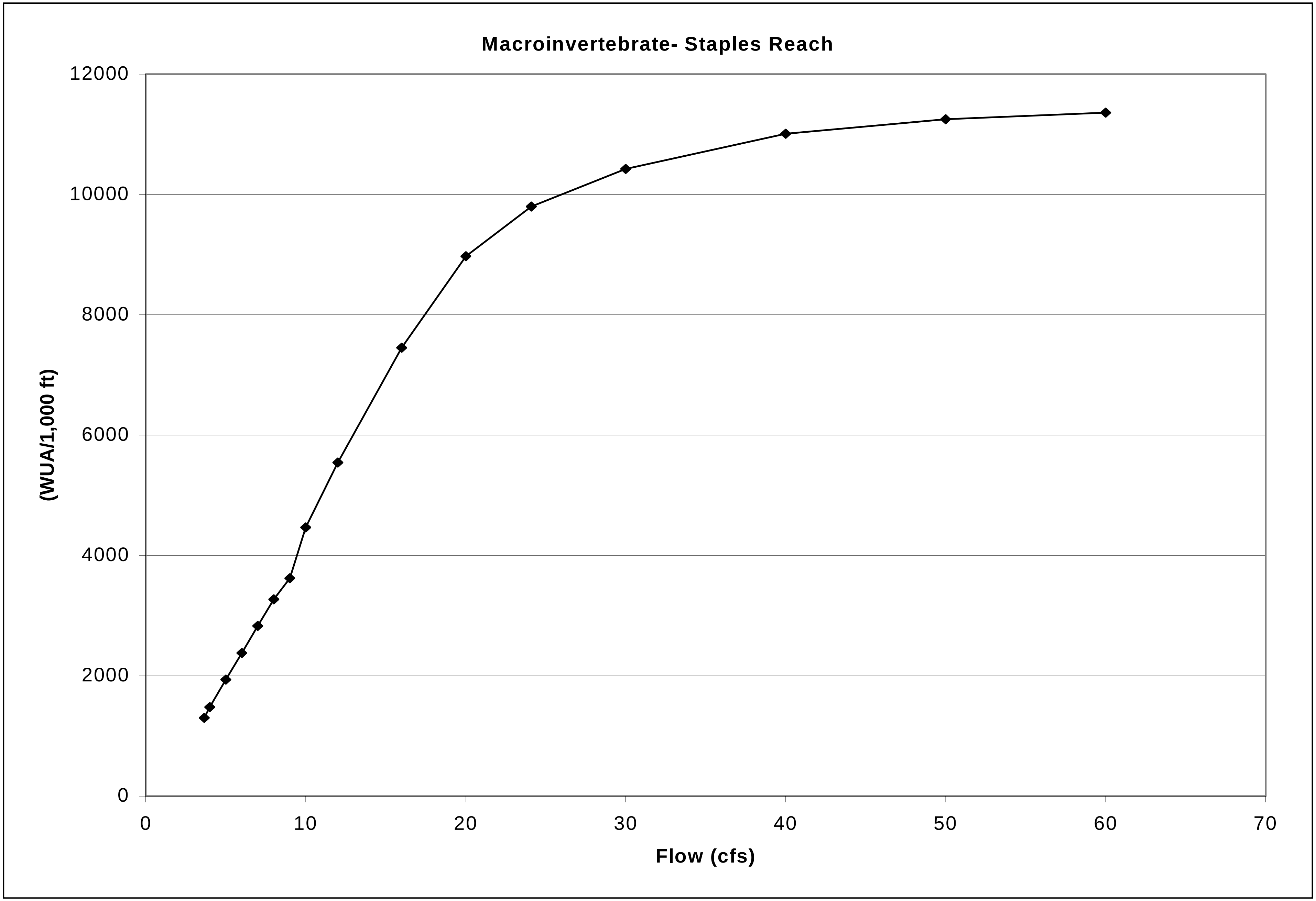


Figure 14.2.5-1: Staples Reach, Macroinvertebrates, WUA versus Flow Curve

15.0 Evaluation of Habitat Results

The purpose of this section of the report is to analyze and discuss the results of the IFIM study to determine a range of flows below the Diversion Dam that meet habitat needs in the Saugus River. The WUA versus flow relationships discussed in the previous section show a range of flows that maximize habitat (WUA) for a given species and life stage. This section analyzes the quantity and quality of habitat for various species/life stages, using the available habitat data, to narrow the range of flows considered.

15.1 Diversion Dam Reach- Discussion of Habitat Results

Shown in Table 15.1-1 (Diversion Dam Reach) is the flow that provides the maximum WUA for each species and life stage (second column). The table also depicts the range of flows that provide 95%, 90% and 80% of the maximum habitat.

Based on Table 15.1-1, a series of nine flows ranging from 4 to 50 cfs were chosen and the habitat values as a percentage of maximum habitat were calculated for each species/life stage analyzed. This information is presented in Table 15.1-2.

It is apparent that several species (adult fallfish, juvenile common shiner, fry/juvenile white sucker and macroinvertebrate) evaluated are the controlling species/life stages in terms of limited habitat at the identified flows. For these species/life stages, the peak WUA occurs at a flow higher than 70 cfs (the maximum simulated flow).

A discussion follows on flows that would fulfill habitat requirements for the various species and life stages evaluated in this study. In general, flows that provide up to 80% of the peak habitat are considered good and are used as a threshold in this study.

<u>Longnose Dace</u>
At a flow of 12 cfs, up to 84%, 96%, 98% and 89% of the peak habitat is available for life stages of S&I, fry, juvenile and adult, respectively. More than 80% of peak habitat is available for all life stages up to flows of 24 cfs.

<u>Fallfish</u>
At a flow of 20 cfs, up to 84%, 98%, and 81% of the peak habitat is available for life stages of S&I, fry and juvenile, respectively. Peak habitat for adult fallfish occurs at flows greater than 70 cfs. During the majority of the year, natural flows in the watershed are well below 70 cfs (further discussion on natural flow availability follows in Section 16.0).

<u>Common Shiner</u>
The flow requirements to optimize S&I habitat occurs at 8.2 cfs, whereas flow needs for fry are much higher- closer to 60 cfs. Common shiner typically spawn during the months late May, June and early July and fry are present from June-August. Natural flows during the fry life stage will be much lower than 60 cfs.

White Sucker and Macroinvertebrates

Flows above 70 cfs are needed to optimize habitat for all life stages of white sucker (except the fry life stage) and macroinvertebrates. Again, natural flows of this magnitude are not present in the summer, and in fact rarely occur throughout the year, except during high runoff events.

Table 15.1-1: Flow versus Percentage of Maximum Weighted Usable Area (WUA) *Diversion Dam Reach*

Species/Life Stage	Maximum WUA Flow (cfs)	Range of Flows providing 95% of Maximum WUA (cfs)	Range of Flows providing 90% of Maximum WUA (cfs)	Range of Flows providing 80% of Maximum WUA (cfs)
Diversion Dam Reach				
Longnose Dace:				
Spawning & Inc.	20	15.0 - 27.2	13.6 - 30.3	10.9 - 35.8
Fry	20	11.0 - 41.1	8.9 - 66.0	6.2 - >70
Juvenile	16	10.9 - 20.9	9.3 - 23.7	7.4 - 29.5
Adult	20	14.8 - 28.5	12.5 - 32.8	9.6 - 42.5
Fallfish:				
Spawning & Inc.	40	28.8 - 55.7	23.9 - 64.7	17.6 - >70
Fry	16	11.1 - 21.6	8.8 - 24.1	<4 - 31.9
Juvenile	50	27.9 - 65.9	24.7 - >70	19.6 - >70
Adult	70+	>70	>70	>70
Common Shiner:				
Spawning & Inc.	8.2	5.9 - 9.2	5.7 - 10.1	5.2 - 11.7
Fry	60	54.9 - >70	49.7 - >70	38.7 - >70
Juvenile	70+	>70	>70	>70
White Sucker:				
Spawning & Inc.	60	37.8- >70	25.4- >70	17.5- >70
Fry	4	4.2- >70	4.5- >70	4.9- >70
Juvenile/Adult	70+	>70	>70	>70
Macroinvertebrate	70+	>70	>70	>70

Table 15.1-2: Percentage of the Maximum Weighted Usable Area (WUA) found for flows of 4, 8.2, 12, 16, 20, 24, 30, 40 and 50 cfs–*Diversion Dam Reach*

Species/Life Stage	Percentage of Maximum Habitat (%)									
	Maximum WUA Flow (cfs)	4 cfs	8.2 cfs	12 cfs	16 cfs	20 cfs	24 cfs	30 cfs	40 cfs	50 cfs
Diversion Dam Reach										
Longnose Dace										
S&I	20 cfs	26%	66%	84%	98%	100%	99%	91%	72%	56%
Fry	20 cfs	83%	88%	96%	99%	100%	98%	97%	95%	93%
Juvenile	16 cfs	61%	85%	98%	100%	97%	89%	79%	66%	55%
Adult	20 cfs	48%	73%	89%	97%	100%	99%	93%	82%	73%
Fallfish										
S&I	40 cfs	34%	57%	71%	77%	84%	90%	96%	100%	98%
Fry	16 cfs	88%	88%	96%	100%	98%	90%	81%	77%	73%
Juvenile	50 cfs	56%	48%	64%	72%	81%	89%	96%	99%	100%
Adult	>70 cfs	??	??	??	??	??	??	??	??	??
Common Shiner										
S&I	8.2 cfs	54%	100%	78%	58%	50%	43%	37%	23%	15%
Fry	60 cfs	22%	20%	30%	41%	49%	57%	68%	82%	90%
Juvenile	>70 cfs	??	??	??	??	??	??	??	??	??
White Sucker										
S&I	60 cfs	29%	53%	67%	77%	84%	89%	92%	96%	99%
Fry	4 cfs	100%	56%	58%	59%	60%	60%	61%	64%	68%
Juvenile	>70 cfs	??	??	??	??	??	??	??	??	??
Macroinvertebrate	>70 cfs	??	??	??	??	??	??	??	??	??

15.2 Staples Reach- Discussion of Habitat Results

Shown in Table 15.2-1 (Staples Reach) is the flow that provides the maximum WUA for each species and life stage (second column). The table also depicts the range of flows that provide 95%, 90% and 80% of the maximum habitat.

Based on Table 15.2-1, a series of six flows ranging from 10 to 30 cfs were chosen and the habitat values as a percentage of maximum habitat were calculated for each species/life stage analyzed- see Table 15.2-2. Unlike the Diversion Dam Reach, the habitat was greater than 80% of maximum for all species and life stages (except macroinvertebrates) over the range of flows evaluated in the Staples Reach. In general, flow needed to maintain habitat requirements in the Staples Reach were much lower than the Diversion Dam Reach.

Longnose Dace, Fallfish, and Common Shiner

At a flow of 10 cfs, up to 88%, 96%, 100% and 88% of the peak habitat is available for life stages of longnose dace S&I, fry, juvenile and adult, respectively. Similarly, at the same flow of 10 cfs, up to 84%, 100%, 85% and 80% of the peak habitat is available for life stages of fallfish S&I, fry, juvenile and adult, respectively. Lastly, at 10 cfs, up to 92%, 83% and 100% of the peak habitat is available for life stages of common shiner S&I, fry and juvenile, respectively. Overall, 10 cfs will provide 80% or more of the peak habitat for all life stages of longnose dace, fallfish and common shiner.

White Sucker

At a flow of 10 cfs, up to 94% and 92% of the peak habitat is available for life stages of fry and juvenile. However, only 38% of the peak habitat is available for the S&I life stage at a flow of 10 cfs. Not until flows are in the 16 cfs range does 80% of the peak habitat become available.

Macroinvertebrate

A flow greater than 60 cfs is needed to maximize macroinvertebrate habitat.

Table 15.2-1: Flow versus Percentage of Maximum Weighted Usable Area (WUA) *Staples Reach*

Species/Life Stage	Maximum WUA Flow (cfs)	Range of Flows providing 95% of Maximum WUA (cfs)	Range of Flows providing 90% of Maximum WUA (cfs)	Range of Flows providing 80% of Maximum WUA (cfs)
Staples Reach				
Longnose Dace:				
Spawning & Inc.	24	13.2 - 26.9	10.8 – 29.7	9.4 – 36.6
Fry	12	9.9 - 20.4	9.5 – 22.5	7.4 – 29.1
Juvenile	10	9.3 – 12.9	5.3 – 14.8	4.0 – 18.0
Adult	24	14.6 – 30.9	11.1 – 38.3	8.4 – 48.9
Fallfish:				
Spawning & Inc.	30	27.3 – 41.6	24.7 – 46.3	7.0 – 56.5
Fry	10	8.2 – 15.2	7.6 – 20.8	6.5 – 27.6
Juvenile	30	21.2 – 38.1	15.1 – 45.0	8.7 – 55.9
Adult	30	18.3 – 45.1	15.2 – 57.9	8.4 - >60
Common Shiner:				
Spawning & Inc.	12	10.7 – 12.7	9.9 – 13.5	9.6 – 14.9
Fry	40	19.2 – 59.4	16.7 - >60	8.5 - >60
Juvenile	10	6.2 – 12.1	5.5 – 13.8	4.5 – 23.3
White Sucker:				
Spawning & Inc.	24	19.8 – 40.9	18.2 – 40.9	15.2 – 52.3
Fry	3.6	<3.6	<3.6	<3.6
Juvenile/Adult	12	10.7 – 14.9	9.4 – 18.2	6.9 – 22.5
Macroinvertebrate	60+	>60	>60	>60

Table 15.2-2: Percentage of the Maximum Weighted Usable Area (WUA) found for flows of 10, 12, 16, 20, 24, and 30 cfs- *Staples Reach*

Species/Life Stage	Maximum WUA Flow (cfs)	Percentage of Maximum Habitat (%)					
		10 cfs	12 cfs	16 cfs	20 cfs	24 cfs	30 cfs
Staples Reach							
Longnose Dace							
S&I	24 cfs	88%	93%	99%	98%	100%	89%
Fry	12 cfs	96%	100%	99%	73%	86%	79%
Juvenile	10 cfs	100%	97%	87%	96%	67%	52%
Adult	24 cfs	88%	92%	97%	96%	100%	96%
Fallfish							
S&I	30 cfs	84%	85%	85%	86%	89%	100%
Fry	10 cfs	100%	99%	94%	92%	83%	78%
Juvenile	30 cfs	85%	88%	91%	95%	96%	100%
Adult	30 cfs	80%	84%	92%	98%	96%	100%
Common Shiner							
S&I	12 cfs	92%	100%	73%	45%	19%	11%
Fry	40 cfs	83%	88%	88%	97%	86%	96%
Juvenile	10 cfs	100%	95%	84%	82%	75%	77%
White Sucker							
S&I	24 cfs	38%	69%	83%	95%	100%	99%
Fry	3.6 cfs	94%	83%	72%	65%	59%	58%
Juvenile	12 cfs	92%	100%	93%	87%	76%	73%
Macroinvertebrate	> 60 cfs	??%	??%	??%	??%	??%	??%

16.0 Discussion and Recommendations

Background

The Saugus River is located in an urban area and has been impacted by human activities for over 300 years. Several public water supply sources are located in the Saugus River Basin. Most of the water removed from the river directly, or indirectly from ground water sources and ponds does not return to the watershed but is discharged out of basin to wastewater treatment facilities. In addition, development has altered wetlands, culverted the river beneath major roads, and placed barriers such as dams across the river. Surface water features in the watershed are manipulated for flood control. The magnitude and timing of river flow has been altered as a result of these human activities. Despite its location in a heavily developed urban area, large tracts of open space remain along the river corridor, including golf courses, state reservations, a national park, and vast areas of protected wetlands. Available water quality data suggest that river quality is suitable to maintain a warm-water fishery and an inspection shows that fish passage is available along the approximately five river miles from the fresh-water limit near the Saugus Ironworks to the LWSC Diversion Dam at the Sheraton golf course in Wakefield. Historic records indicate a once-prolific alewife run occurred in the Saugus River annually. Recent surveys show a lack of a thriving fish population in the river, however. This study determined that although natural flow conditions probably did not provide optimal fish habitat, improvements to the timing and magnitude of flow could be made to increase fish populations in the river as well as improve water quality. The impacts of past human development cannot be undone; water resources must be reasonably allocated among human and environmental needs. Opportunities exist to improve aquatic habitat by managing river flow. Even modest modifications toward the natural flow regime (such as maintaining a minimum summer flow) may result in vast improvements in fish populations and habitation of the river. This in turn will support a healthy watershed ecosystem.

As the habitat survey results of the Diversion Dam Reach show, flows in the range of 12-20 cfs provide a large percentage of the peak habitat for many species and life stages. However, many other species in the Diversion Dam Reach require flows in excess of 60 cfs. Alternatively, in the Staples Reach, a flow of 10 cfs provides over 80% of the peak habitat for all species except macroinvertebrates and the S&I life stage of white sucker.

Before making any flow recommendation, consideration needs to be given to the natural hydrology of the watershed, and more specifically what the water availability is throughout the year at the Diversion Dam. In Section 5.6 (Regulated and Unregulated Hydrology) of this document, the unregulated hydrology of the watershed was quantified at the USGS gage by adjusting the flows recorded at the USGS gage to account for water withdrawals within the watershed. Even in its regulated condition, a seasonal range and variation of flow occurs in the Saugus River, although flows are impacted by withdrawals at certain times.

Shown in Figure 16.1-1 are the average and median monthly flows calculated for the USGS gage based on unregulated conditions (period of record 3/1/1994-12/31/1999). It should be noted that the flow values provided in Figure 16.1-1 are based on roughly six years of flow and water withdrawal (diversion) data. Typically, hydrologists rely on a minimum of 25 years of record upon which to make decisions.

Between the Staples Reach and the USGS gage there are no tributaries, only minor local inflow. Thus, the drainage area at the Staples Reach is very similar to the USGS gage- approximately 23.3 mi^2. For purposes of this study, it was assumed that the drainage area was effectively the same. Overlain on Figure 16.1-1 is the flow (10 cfs) at which 80% or more of the peak habitat is provided for all species and life stages (except white sucker, S&I and macroinvertebrates) in the Staples Reach.

As Figure 16.1-1 shows during the months of July and August, the average unregulated flow in the Saugus River near the Staples Reach is 10 cfs or less. During the spring and early summer, the fish examined in this study will be spawning, with fry emerging and foraging during the July through August period. During the balance of the year, average flows in the Staples Reach are typically above 10 cfs.

Shown in Figure 16.1-2 are the average and median monthly flows calculated for the LWSC Diversion Dam Reach. These flows were computed by adjusting the unregulated flows at the USGS gage to represent flow at the Diversion Dam. For example, the average unregulated January flow at the USGS gage is 58.2 cfs. Thus, the flow at the Diversion Dam was estimated as follows: 58.2 cfs x (10.5/23.3) or 26.2 cfs, where 10.5 and 23.3 are the drainage area in square miles at the Diversion Dam and USGS gage, respectively. Prorating flows based on drainage area is commonly used by hydrologists, so long as flow conditions are unregulated (i.e. not affected by water withdrawals, hydropower peaking, storage reservoirs, etc).

Overlain on Figure 16.1-2 are the flows at which 80% or more of the peak habitat is provided at the Diversion Dam reach for the various species and life stages evaluated. As noted earlier for several species (fallfish-adult, common shiner-fry and juvenile, white sucker- all life stages except fry, and macroinvertebrates), the peak habitat occurs at a flow greater than 60 cfs. As Figure 16.1-2 shows, the unregulated flow at the Diversion Dam is well below the habitat needs for all of the species during the period June-September. In fact, the flow is below 8 cfs during most of the summer even without water withdrawals.

United States Fish and Wildlife Service Interim Regional Flow Policy

The United States Fish and Wildlife Service (USFWS) has developed the New England Regional Flow Policy, which sets default minimum flows on a flow per square mile basis if no USGS gage or site-specific study has been conducted.

The USFWS has used historical flow records for New England to describe stream flow conditions that will sustain and perpetuate aquatic fauna. Low flow conditions occurring in August typically result in the most stress to aquatic organisms, due to high water temperatures, and low dissolved oxygen, food supply and available habitat area. Over the long term, stream organisms have evolved to survive these periodic adversities without major population change. The USFWS has therefore designated the median August flow as the Aquatic Base Flow

(ABF)[29]. The USFWS has assumed that the ABF will be adequate throughout the summer (at a minimum), unless additional flow releases are necessary for fish spawning and incubation. In summary, the USFWS has set minimum flow rates as a function of drainage area as shown in Table 16.1-1. Also shown in Table 16.1-1 is the USFWS recommended flow rates at the Diversion Dam and in the Staples Reach absent any alternative analysis.

Table 16.1-1: USFWS New England Regional Flow Policy. Default Minimum Flows

Period	Fall/Winter (Oct-Mar)	Spring (Apr)	Summer (May-Sept)
Flow per square mile	1.0 cfsm[30]	4.0 cfsm for the entire applicable spawning and incubation periods	0.5 cfsm as derived from the median August Flow
Estimated ABF Minimum Flows at the Diversion Dam (10.5 mi^2)	10.5 cfs	42 cfs	5.25 cfs
Estimated ABF Minimum Flows near the Staples Reach (~23.3 mi^2)	23.3 cfs	93.2 cfs	11.65 cfs

As the policy states, the USFWS will default to using the ABF minimum flow values, except when an existing USGS gage or site-specific study is conducted. The USFWS will default to the site-specific ABF based on computing the average of the median monthly August flow from the USGS gage, however, there are two requirements at the gage site. First, the USGS gage must reflect free-flowing conditions—i.e., the river must be unregulated. As described above, the unregulated flow at the Saugus USGS gage was quantified, so effectively, the flow data is representative of free-flowing conditions. Second, the USFWS requires that a minimum of 25 years of flow record. In this case, there is approximately 6 years of available flow data. Recognizing the limitations on the short period of record, the average of the median monthly flows were computed at the Diversion Dam and USGS gage as shown in Table 16.1-2 (the unregulated median monthly flow per square mile is also shown). The values in the table represent calculated flows without the LWSC diversion and other water supply withdrawals in the basin.

Table 16.1-2: Average of the Median Monthly Flow at the Diversion Dam and Saugus USGS Gage based on the Period of Record 3/1/1994-12/31/1999 (Note: Flow values are based on an unregulated Saugus River)

Location	Median Monthly Flow (cfs) based on Period of Record 3/1/1994-12/31/1999											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
[31]Flow/mi^2	2.26	2.05	2.52	2.25	1.51	0.53	0.22	0.20	0.42	0.81	1.36	1.49
Diversion Dam (10.5 mi^2)	23.7	21.5	26.5	23.6	15.9	5.5	2.3	2.1	4.4	8.5	14.2	15.7
USGS Gage (23.3 mi^2)	52.7	47.7	58.8	52.5	35.3	12.3	5.1	4.6	9.8	18.8	31.6	34.8

[29] The ABF is derived from the average of the median August monthly flow records.
[30] cfsm- cfs per square mile of drainage area.
[31] Flow values are based on an unregulated Saugus River.

A direct interpretation of the ABF policy would result in a median August flow at the Diversion Dam of 2.1 cfs (4.6 cfs at USGS Gage). The lowest flow during the fall/winter period (assumed to run from October to March) is 8.5 cfs (18.8 cfs at USGS Gage) and the lowest spring flow (April) is 23.6 cfs (52.5 cfs at USGS Gage).

The low watershed yield of Saugus River during the summer essentially limits the quantity and quality of aquatic habitat in the reaches examined in this study. It should also be noted that a large portion of the drainage area above the Diversion Dam consists of impounded or open water, which further contributes to the loss of water via evaporation and evapotranspiration during the summer. Sizeable open water areas include:

Lake Quannapowitt	750 acres
Pillings Pond	99 acres
Reedy Meadows	540 acres
	1,389 acres or 2.2 mi^2

Surface water evaporation occurs at Lake Quannapowitt and Pillings Pond, while in the Reedy Meadows area evapotranspiration from plants also reduces the quantity of water arriving at the Diversion Dam. One inch of evaporation from a surface area of 1,389 acres is equivalent to 58.35 cfs-day. Thus, if two inches of evaporation were to occur during July (for example), it would equate to a loss of 3.76 cfs from the basin. A 2-inch drop in pond/wetland water levels due to evaporation is not uncommon during the summer months.

Evaluation of Other Gaged Rivers

As Table 16.1-2 shows, the median August flow per square mile in the Saugus River (unregulated) is 0.20 cfsm. The ABF cfsm factors for other rivers in close proximity to the Saugus River were also computed for their respective periods of record. The purpose for computing these values is to determine an order of magnitude of the August cfsm. It should be clearly noted that these rivers are subject to regulation such as water withdrawals, diversions for industrial use, etc. Thus, they do not provide a true indicator of the natural median August flow- again we are only examining these gages to determine an order of magnitude. The August cfsm factor was computed for the Parker, Ipswich and Aberjona Rivers for three different periods of record- the full period of record, and an earlier period of record up to 1960, and from 1994-1999 (see Table 16.1-3). The purpose for computing the median August cfsm for the pre-1960's period is it was generally assumed that water withdrawals from these watersheds would be less and thus the rivers would be more reflective of an unregulated system. The period 1994-1999 was selected since it is the same period of record used in the Saugus River analysis.

Table 16.1-3: August cfsm factors for other Rivers in close proximity to the Saugus River

Gage Name	Drainage Area (mi^2)	Period of Record	August cfsm factor
Parker River at Byfield, MA	21.3	1945-2000	0.21
		1945-1960	0.23
		1994-1999	0.05
Ipswich River at South Middleton, MA	44.5	1938-2000	0.21
		1938-1960	0.23
		1994-1999	0.12
Aberjona River at Winchester, MA	24.7	1939-2000	0.22
		1939-1960	0.15
		1994-1999	0.23

Except for the Aberjona River, there is little difference in the pre-1960's and full period of record August cfsm values. The unregulated Saugus River median August flow per square mile (0.20) for the period 1994 to 1999 is higher than the Parker and Ipswich gages, and close to the Aberjona gage during the same period of record (it should be noted that the 0.20 cfsm value is based on a deregulated river, whereas the other gages are based on regulated systems).

Alewife Migration

One of the management objectives for the Saugus River is to restore and maintain an alewife/blueback herring run during the spring. Thus, it is important to identify the timing of the run during the spring, which is primarily dependent on flow, water temperature and hours of daylight. A review of the literature suggests that alewives start their upmigration in late March (Pardue, G, 1983) depending on the coastal location. In addition to the available literature, the Parker River Clean Water Association has collected data to document the timing of alewife runs in the Parker River. The Parker River is a coastal stream located approximately 20 miles north of the Saugus River. During the spring, river herring (alewives and blueback herring) return from the Atlantic to spawn in the Parker River and its tributaries. Beginning in April and continuing into May, alewives ascend the Parker River on their way to spawn in the headponds where they were born. A review of the timing of the alewife run for 1973, 1974, 1997 and 1998 (partial) suggests that upmigration occurs from mid-April to mid-May. It should be noted that count data is not available prior to April 15. Shown in Figure 16.1-3 is the cumulative count of alewives as recorded at the first dam on the Parker River- Central Street Dam.

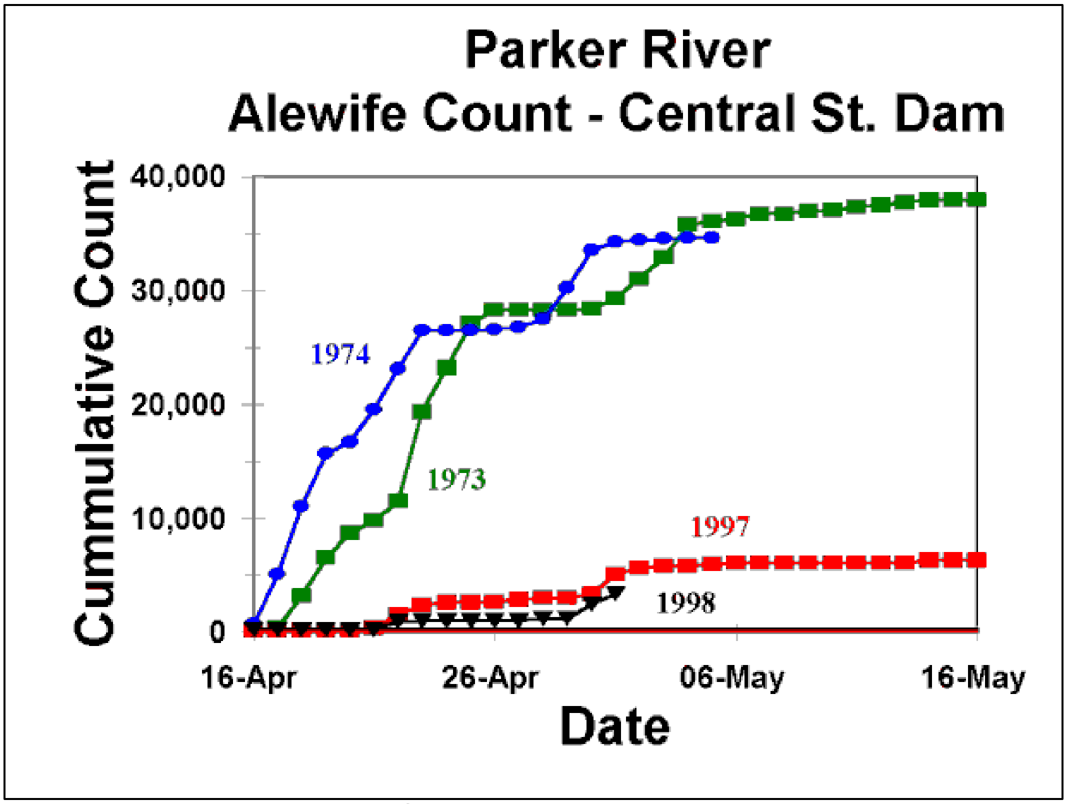


FIGURE 16.1-3: Cumulative Alewife Counts in the Parker River Basin at Central Street Dam

As Figure 16.1-3 shows, the bulk of the run occurs in late April (perhaps earlier since counts began in mid-April) and early May and slows around May 6. In summary, when considering flow recommendations, the months of April and May are assumed to be the major time periods for supporting a river herring run. Following the upstream migration and spawning, the adult herring require flow to migrate downstream and return to the ocean.

<u>Flow Recommendations</u>

The instream flow study evaluated the flow needs for the various species and life stages examined in this study. For many of the species and life stages, the flow needed to provide an adequate quantity and quality of habitat (particularly in the Diversion Dam Reach) far exceeds the natural flow of the watershed during the summer period.

Taking into account the physical landscape of the basin above the Diversion Dam, the natural hydrology of the watershed, the results of the instream flow study and the timing of the alewife run, shown in Table 16.1-4 is the recommended minimum flows for the LWSC Diversion Dam.

Table 16.1-4: Recommended Minimum Flows at the LWSC Diversion Dam

Period	Jun 1-Sep 30	Oct 1-Feb 28 (29)	Mar 1-Apr 30	May 1-31
Flow	3 cfs	6 cfs	12 cfs (see Note 3)	10 cfs (see Note 3)

Notes:
1. Minimum flows should be provided on a continuous basis
2. The minimum flows should be equivalent to total inflow to the Diversion Dam or the minimum flow listed in this table, whichever is less. For example, if total inflow to the Diversion Dam is 1 cfs in June, then the discharge at the Diversion Dam should be 1 cfs. If the total inflow to the Diversion Dam is 10 cfs in June, then the discharge at the Diversion Dam should be 3 cfs.
3. The original March 1-April 30 flow recommendation was set at 24 cfs, the approximate median monthly flow during these months. In addition, the original May flow recommendation was set at 6 cfs. However, LWSC was concerned that a 24 cfs release would impair their ability to refill their reservoirs for water supply needs. The recommendations reflect a compromise of water supply demands, and flow needs to restore and maintain the river herring run. As noted later in this document, it is highly recommended that the recommended spring minimum flows be implemented and that a formal river herring monitoring study be conducted over the next few years. Monitoring should be conducted to ensure that the recommended spring minimum flows are providing sufficient flow and particularly water depth to provide upstream passage needed to maintain and restore the Saugus River alewife/blueback herring run. Similarly, it is also highly recommended that an evaluation of the flow needs of outmigrating juvenile herring in the fall be conducted to ensure that there is sufficient depth to pass downstream (when the recommended minimum flow is 6 cfs). Although access to the headpond for spawning and juvenile development is not presently available because of the LWSC dam, if a fishway is provided in the future, maintenance of fall flows for juvenile outmigration will be necessary

The minimum flow of 3 cfs (June 1-September 30) was selected primarily due to the natural hydrology of the watershed. The June 1-September 30 period also matches the timing of natural flows in the Saugus River. A direct interpretation of the ABF policy would yield an August median flow at the Diversion Dam of 2.1 cfs, however, this is based on the period of record from 1994-1999. In Section 2 of this document, the long-term monthly precipitation was presented for both the Lynn (129 year record) and Wakefield (64 year record) gages and was compared to the 1994-2000 period of record. At the Lynn gage, the July and August precipitation for the 1994-2000 period was 5.4% and 40.2% below the long-term average, respectively. Similarly, at the Wakefield gage, the July and August precipitation for the 1994-2000 period was 21.4% and 27.8% below the long-term average, respectively. In summary, precipitation and runoff during the July-August period of record (1994-2000) was below the long-term average. Although a direct computation of the median August flow is 2.1 cfs at the Diversion Dam, it is based on drier than normal conditions. Thus, a slightly higher minimum flow was selected to be more representative of the long-term hydrology.

The minimum flow of 6 cfs (Oct 1-Feb 28) was selected based on the instream flow study results. During the period October 1-February 28, only juvenile and adult fish will be utilizing overwinter habitat in the Saugus River. A flow of 6 cfs will be insufficient for habitat needs in the 232-foot-long Diversion Dam Reach, however, it should provide a large percentage of the habitat in the Staples Reach (when the intervening flow is included) as well as the approximate 5 miles of river examined in this study. It should be noted that the Diversion Dam Reach is not necessarily typical of the entire Saugus River. The gradient is much steeper than the majority of the river. In fact, most of the Saugus River consists of slow moving runs, more closely resembling the Staples Reach. The incremental drainage between the Diversion Dam and Staples Reach is approximately 12.8 mi^2. During the period October-February, the lowest flow per square mile occurs in October – 0.81 cfsm (see Table 16.1-2). Using this factor, the incremental drainage would provide approximately 10.4 cfs (12.8 x 0.81). Thus, total flow at the Staples Reach would be 6 cfs (from the Diversion Dam) plus 10.4 cfs (incremental inflow) or approximately 16 cfs. At 16 cfs, 84% or higher of the peak habitat is available for the juvenile and adult life stages of all species examined in the Staples Reach (juvenile longnose dace- 87%, adult longnose dace-97%, juvenile fallfish-91%, adult fallfish-92%, juvenile common shiner-84%, juvenile white sucker-95%).

As stated earlier, the original March 1-April 30 flow recommendation was 24 cfs. This flow recommendation, which is the median unregulated flow for the combined months of March and April, was based on basin hydrology and not specific resource management objectives. The draft report also recognized that a minimum flow of 24 cfs would greatly impact LWSC's ability to withdraw water during a period when their reservoirs are being refilled.

Subsequent to issuance of the draft report there were further discussions regarding the flow recommendations and competing water uses. During the spring period those competing uses include: a) to restore and maintain a successful alewife run, b) maintaining LWSC's water supply diversions, and c) to recharge LWSC's reservoirs. To strike a balance between public water supply needs and environmental needs, the flow recommendations were revised to 12 cfs in March and April and 10 cfs in May.

If flows of 12 cfs and 10 cfs are provided during April and May, when alewives are migrating, there needs to be sufficient depth (or a zone of passage) to ensure movement to the LWSC Diversion Dam. Phil Brady of the Massachusetts Division of Marine Fisheries was contacted regarding the minimum depth needed for adult alewives to successfully migrate upstream. Mr. Brady indicated that a minimum depth of 8 to 9 inches is needed through hydraulic controls and riffle reaches, where depths are typically the lowest. It should be noted that most of the riffle areas (where depths are typically shallow) were evaluated as part of this study. Other portions of the river (i.e. runs) will have water depths greater than 8 to 9 inches at the target flows. The only other location where depth may be a concern (other than the study riffle reaches) is at the riffle near the Camp Nihan footbridge. Based on a review of cross-section plots, a flow of 10 cfs would provide over 9 inches of depth at portions of all of the transects examined in this study. In general, the minimum passage depths will be provided through the thalweg of the riffles at a flow of 10 cfs.

After spawning is complete, adults depart within a few weeks. Similar to upstream passage depths, sufficient depth (flow) must also be maintained for outmigrating adults.

It should also be noted that during April flows below the Diversion Dam might be greater than 12 cfs, depending on rainfall, snowmelt and runoff. The estimated average monthly unregulated flow at the Diversion Dam for April is 25.9 cfs (median flow is 23.6). In addition, the average LWSC withdrawal during April is 8.5 cfs. Thus, for April the minimum flow (12 cfs) plus the average withdrawal (8.5 cfs) is collectively equal to 20.5 cfs, which is less than the estimated unregulated flow of 25.9 cfs. LWSC may also release water in response to upstream flooding concerns.

To support the spring flow recommendations, it is recommended that a formal annual alewife monitoring/count program be implemented on the Saugus River after implementation of the spring minimum flow recommendations for monitoring purposes. It should be noted that during the spring 2002, the SWRC launched a fish spotter program to identify the presence and timing of anadromous fish such as alewife and blueback herring. We recommend expansion of this program to include a more formal alewife-monitoring program. In addition to counting alewives, flow data at the USGS gage at the Ironworks and releases from the Diversion Dam should also be recorded (flow and/or stage) to develop relationships between alewife counts and flow. Water temperature monitoring could also be conducted in an effort to establish a correlation with the timing of the herring run. Data for river herring runs in other nearby rivers could also be reviewed to compare the relative success of the recommended spring flows to re-establish the herring run compared to runs in other rivers. After a few years of data collection and analysis, further modification to the magnitude and timing of the spring minimum flows might be needed to ensure adequate upstream and downstream movement of adults. Also, as part of the monitoring plan, the riffle reach at the Camp Nihan footbridge should be evaluated to ensure that the sufficient depths are available to successfully pass alewives upstream.

In addition to the monitoring study of upstream migration, it is also recommended that a monitoring study of outmigrating juvenile alewives be conducted if a fishway is provided at the LWSC dam. Outmigration typically occurs in the fall, when the recommended minimum flow is 6 cfs. Similar to upstream passage, sufficient depth must be available for juveniles to migrate to the ocean. It may be necessary to restock alewife in the river to re-establish a run comparable in size to the historic populations. Restocking can be requested from the Massachusetts Division of Marine Fisheries once a fishway is established.

In summary, it is suggested that adaptive management principles be applied to this project. If, after a few years of implementing the recommended minimum flows and conducting alewife-monitoring studies, the flows do not provide the desired affect, perhaps some further modification to the minimum flows might be needed or some stream restoration techniques might be considered.

Although one of the management objectives is to maintain an alewife run, the Diversion Dam currently impedes further upstream movement. As noted later, the Army Corps of Engineers is considering fish passage at the Diversion Dam, presumably to pass alewives to the upstream impoundment. No information is currently available on the quantity or quality of habitat in the impoundment nor is it known whether alewives can ascend to the base of Lake Quannapowitt

Dam [32](although not confirmed, based on input from various agency personnel there is no clear channel through Reedy Meadows to allow fish to move to the base of Lake Quannapowitt Dam). It is recommended that quantity and quality of alewife habitat above the Diversion Dam be evaluated before fish passage facilities are constructed.

If the spring minimum flow is maintained and fish passage is not provided, it is possible that adult alewives could be netted at the base of the Diversion Dam and then physically moved to the upstream impoundment, however, this is not recommended. One other consideration is that juvenile alewives that rear and grow in the impoundment will need to migrate downstream to the ocean in the fall. Again, if downstream passage is not provided, it is unknown how these juvenile fish will be passed at the Diversion Dam, except through the sluice gate or over the spillway[33]. The sluice gate opens from the bottom and discharge through the gate would be under pressure. Juvenile alewives are more surface water orientated and it unknown if they would pass through a pressurized gate, roughly 6 feet below the water surface.

Impact of Recommended Minimum Flows on LWSC

The total inflow to the Diversion Dam is controlled by a variety of sources including:

- discharges from Lake Quannapowitt and Pillings Pond,
- lack of a clear channel through Reedy Meadows affects the timing and perhaps magnitude of flow entering the Diversion Dam,
- the Sheraton Golf Course withdraws water for golf course watering,
- the Lynnfield Center Water District withdraws groundwater in the upper watershed for water supply,
- there are numerous residential wells located upstream of the Diversion Dam, and
- the Wakefield Water Department withdraws water from Crystal Lake. Although Crystal Lake drains into the Saugus River below the Diversion Dam, the unregulated flow values developed for the Diversion Dam were based on prorating the computed unregulated flow at the Saugus USGS gage. The unregulated flow computed at the USGS gage and the instream flow study results were used to set flow recommendations. Remember that the unregulated flow at the Diversion Dam was determined by prorating the computed unregulated flow (by drainage area) at the Saugus USGS gage.

Unless the other sources of regulation upstream of the Diversion Dam were changed, LWSC would effectively be the only entity that would be directly affected by the minimum flow recommendations. For example, during April when the flow recommendation is 12 cfs, Lake Quannapowitt may be refilling since the lake is drawn down in the fall. As such, inflow to the Diversion Dam would reflect less water in the spring than naturally occurs. Similarly, during the summer when the flow recommendation is 3 cfs, the Sheraton Golf Course and Lynnfield Center Water District are withdrawing water, which reduces the net inflow to the Diversion Dam. Also, if an unobstructed channel was established through Reedy Meadows perhaps less

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[32] As noted earlier in this report, historical accounts from the late 1800's and early 1900's indicate that alewives did migrate and utilize Lake Quannapowitt.
[33] It should also be noted that spillage over the dam rarely occurs during this period.

evapotranspiration would occur in the wetland during the summer and the flow rate entering the Diversion Dam would potentially increase.

In summary the flow recommendations will only directly affect LWSC unless other measures are implemented. Listed below are other recommendations that would potentially reduce the impact on LWSC. It should be noted that no analysis has been undertaken to determine how these recommendations may affect other resources (flooding, aquatic habitat, recreation, aesthetics, etc).

- Eliminate the fall drawdown at Lake Quannapowitt such that discharges during the spring resemble natural flow conditions (more water would be available to maintain the spring minimum flows). Alternatively, another consideration is to draw down Lake Quannapowitt in the summer to increase the flow at the Diversion Dam. The same conditions apply to Pillings Pond (eliminate any fall drawdown, increase summer drawdown).
- The Sheraton Golf Course and Lynnfield Center Water District could reduce withdrawals. Some procedure could be implemented where all water users share in reducing their withdrawals.
- LWSC may consider utilizing the Ipswich River water withdrawal more often if Saugus River withdrawals are reduced.
- LWSC and others may consider purchasing water from other sources such as the MWRA.
- An unclogged, free-flowing channel through Reedy Meadows would potentially reduce evapotranspiration and evaporation occurring in the meadow and increase flow delivered to the Diversion Dam.

Under the assumption that upstream conditions were maintained as status quo, the effect of the flow recommendations on LWSC were quantified. Shown in Figure 16.1-4 is a bar graph depicting:

- the average monthly withdrawal by LWSC (period of record: 1/1/94-12/31/99)- gray
- the average monthly unregulated flow at the Diversion Dam (period of record: 3/1/94-12/31/99)- striped
- the recommended minimum flow-dashed line
- the average monthly withdrawal by LWSC plus the recommended minimum flow- black

Referring to Figure 16.1-4, for those months where the average monthly withdrawal by LWSC plus the recommended minimum flow (black bar) exceeds the average monthly unregulated flow (striped bar), LWSC would have to reduce their withdrawal. Thus, on average, during the months of May, August, September and November, LWSC would have to curtail their withdrawals as summarized in Table 16.1-5.

Table 16.1-5: Effect of Flow Recommendation on LWSC Water Withdrawals

Month	May	August	September	November	Total
Average Reduction in flow (cfs and MGD)	1.1 cfs (0.7 MGD)	1.7 cfs (1.1 MGD)	0.6 cfs (0.4 MGD)	2.4 cfs (1.5 MGD)	
Average Reduction in Volume of	21.8 MGM	34.7 MGM	11.2 MGM	46.1 MGM	113.9 MG

flow over the month (MG/month or MGM) (flow x no. of days per month)					

LWSC's average annual withdrawal from the Saugus River for the period 1994-1999 is 1,788 MG. Implementing the flow recommendations will reduce the LWSC's water withdrawal by 6.4% (113.9/1,788) on an annual basis and by 12%, 90%, 10%, and 18% during May, August, September and November, respectively (assuming withdrawals are not increased at other times of the year). During the remaining months, under average conditions, there is sufficient flow in the Saugus River to allow for increased water withdrawals by LWSC to offset the effects of the flow recommendations while still providing the recommended minimum flow.

LWSC may be able to withdraw the same volume of water from the Saugus River as currently used; however, the timing of those withdrawals would be shifted toward more reliance on the winter months notably January and February. In addition, it does not appear that LWSC utilizes their full allowable withdrawal from the Ipswich River (allowable withdrawal period December 1-May 31), which could also be used to supplement the water supply volume. It is recognized that the Ipswich River flow availability is also being investigated at this time as part of another study. The impact of increasing Ipswich withdrawals by LWSC has not been evaluated as part of this study.

Deviation from Flow Recommendations- Emergency Conditions

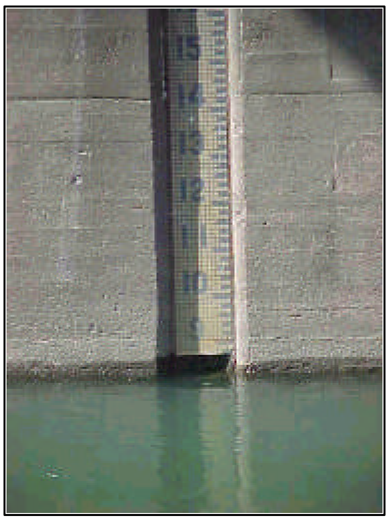
A reduction or elimination of the recommended minimum flows may be required for public safety and health purposes. There may be instances when severe drought conditions may occur where river flows and reservoir storage capacity are extremely low prompting an emergency public safety and health concern. Concerns include the need for drinking water, and maintaining sufficient flow and water pressure for fire protection. In these cases, and after water conservation measures have been exhausted, it is recognized that water supply demands for public health, safety and welfare may outweigh environmental needs. It is not the intent of this report to determine when water supply needs would take higher priority over providing minimum flows. The State already monitors various indices to determine when drought conditions are occurring and would take the necessary measures to uphold public health and safety in the event of a drought emergency. Individual water suppliers manage demands under normal conditions and prior to state declared drought emergency levels.

Similarly, in response to significant precipitation events, LWSC may need to pass flow through the Saugus River to prevent or mitigate flooding, and/or may choose to divert water from the Saugus River into their reservoir system during summer months. These events such as tropical storms may affect the timing of LWSC diversions and subsequent maintenance of minimum flows.

Implementation of Flow Recommendations

To ensure compliance with these flow recommendations it is suggested that a staff gage (similar to that shown in Figure 16.1-5) be placed below the Diversion Dam. A staff gage is basically a ruler attached to the river bank, a bridge piling, or abutment. The river level is measured by reading the markings on the gage, which is then converted to flow via a rating curve. To develop a rating curve, a range of flows (within the recommended flow range) would be measured below the Diversion Dam using flow-metering equipment. Each day, someone could visit the staff gage and visually identify the river stage and convert the stage to flow via the rating curve. A potential location for the staff gage is on the wingwalls of the Diversion Dam.

In addition to the river staff gage, it is suggested that the same type of staff gage also be placed in the headpond above the Diversion Dam. The purpose for placing the gage in the headpond is to determine if the flow recommendations are exceeding the total inflow to the Diversion Dam. If the Diversion Dam gate is set to release 3 cfs, and by establishing a fixed elevation in the headpond, operators will know if total inflow drops below 3 cfs since the headpond elevation will drop. If this occurs, operators would have to adjust the gate opening to better match inflow in accordance with the flow recommendations.



It should be noted that the Diversion Dam headpond is hydraulically connected to Reedy Meadows, which is an important wetland complex. It is unknown what fixed headpond elevation could affect habitat for wetland dependent species, thus further evaluation may be needed before establishing a fixed headpond elevation.

There will be times when the headpond elevation rises, when inflow exceeds the minimum flow. In accordance with the flow recommendations, when this occurs, LWSC can divert water to Hawkes Pond so long as the headpond elevation does not drop below the agreed upon fixed elevation.

Figure 16.1-5: Example Staff Gage

<u>Gate Changes and Ramping</u>

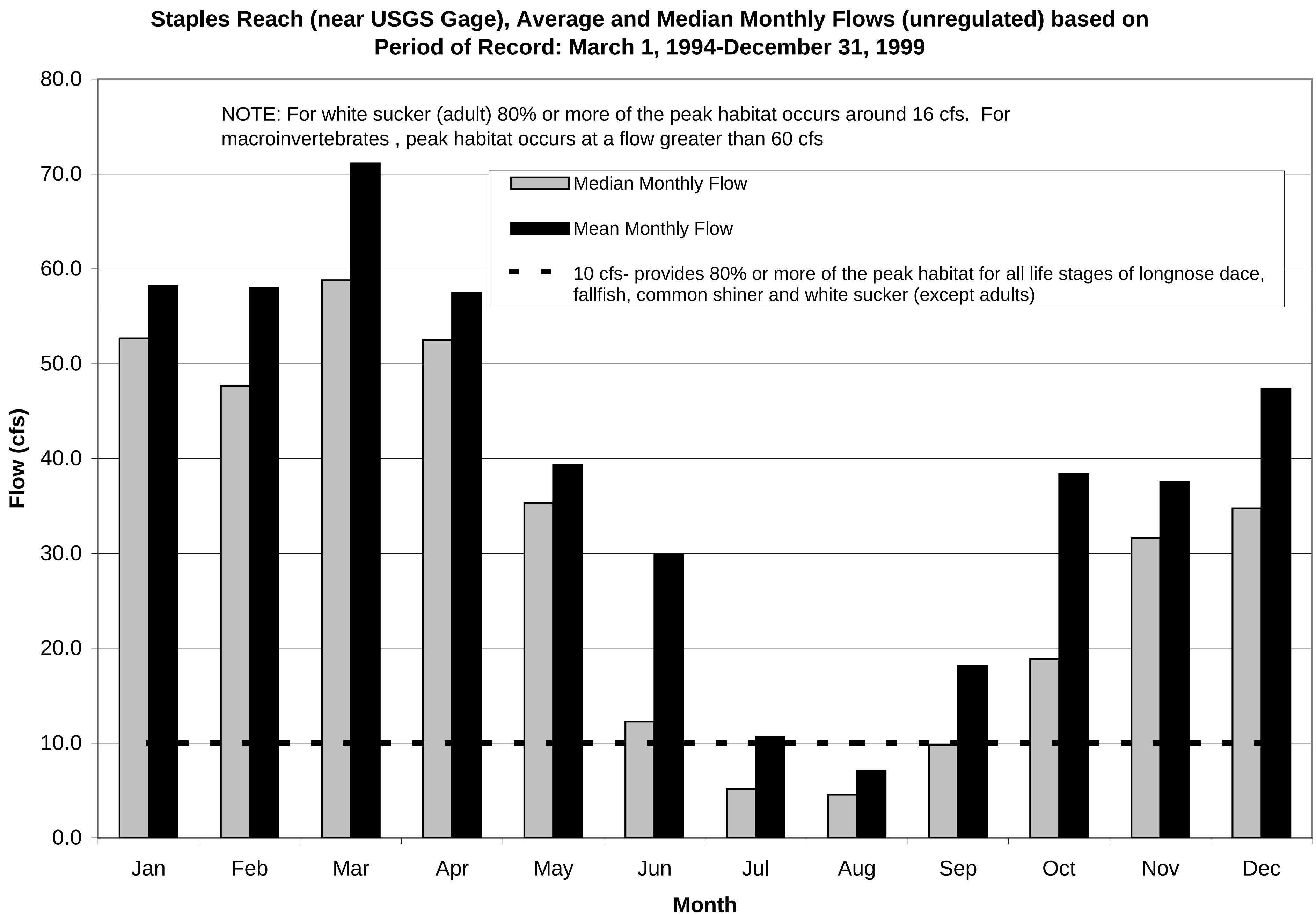
LWSC controls the gate at the Diversion Dam that releases water to the Saugus River. Gate changes can take less than a minute, which can translate into rapidly changing flow conditions in the Saugus River. When the gate opening is adjusted to reduce the release the rapid reduction in flow may cause fish stranding. By slowly reducing the gate opening, fish will have more time to respond to flow changes and will seek deeper waters. Based on the habitat mapping exercise, the main area of stranding concern appears to be the reach directly below the Diversion Dam since the channel slope is steep. In addition, this reach is most directly affected by gate changes due to its close proximity to the gate. Most of the Saugus River is deep and slow enough that fish in other areas will likely have enough time to adjust to flow changes.

The other concern is when the gate opening is increased. During the early summer, when fry are typically present in the river, they feed along the stream edge. If flows are increased quickly, fry will not respond quickly enough to seek shelter.

A ramping rate is not being proposed; rather a simple one-day field exercise could be conducted to determine an acceptable up and down ramping rate. Temporary staff gages could be placed at critical locations (areas where fish could be stranded along the stream margin) in the Diversion Dam Reach and gate changes could be made. The staff gages could be read to determine the rate in which the depth increases and decreases in relation to gate changes.

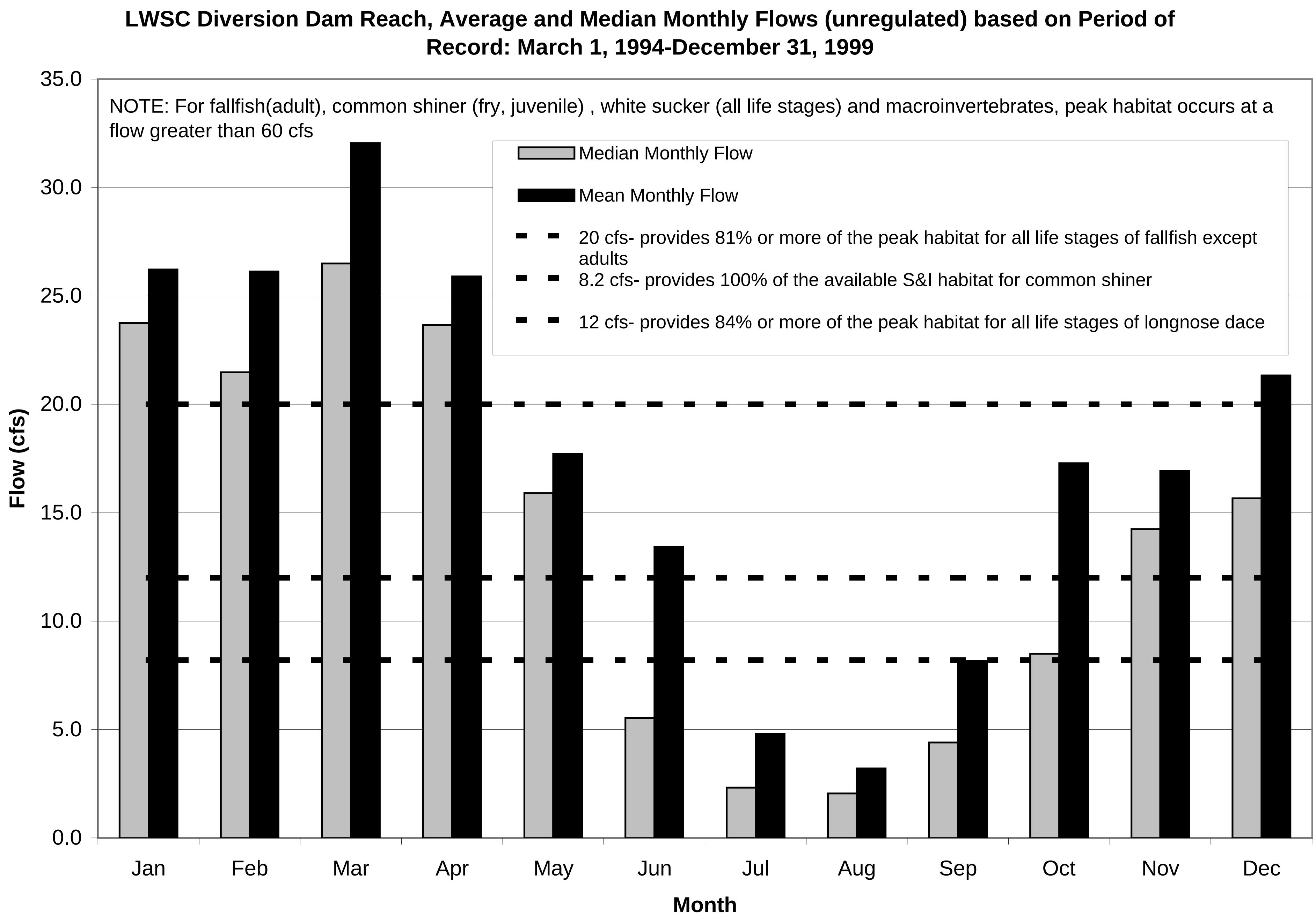
Fish Passage

As noted above, the Army Corps of Engineers may consider installing a fish ladder at the Diversion Dam. The fish ladder would allow primarily migratory fish, such as alewife and blueback herring to seek spawning habitat above the Diversion Dam. The quality and quantity of alewife/blueback herring habitat above the Diversion Dam is unknown. It is recommended that further evaluation of this habitat is needed before constructing a fish ladder. As noted above, alewife and blueback herring migrate from the ocean to freshwater during the period April through May, depending on flow and temperature conditions. Juvenile alewife and blueback herring will return to the ocean when water temperatures cool- typically during September through December. If a fish ladder is installed, the headpond elevation needed to ensure flow in the fishway will have to be determined. In addition, it is unknown what flow may be necessary to move fish up the ladder, although it is assumed that the recommended minimum flows would be passed in the ladder and not the gate.



The Staples Reach is located close to the USGS Gage at the Ironworks-
there are no tributaries just local drainage between the reach and gage.

FIGURE 16.1-1



Diversion Dam flows were determined by deregulating the Saugus USGS Gage (at the Ironworks) and adjusting the deregulated flows based on drainage area to the Diversion Dam

FIGURE 16.1-2

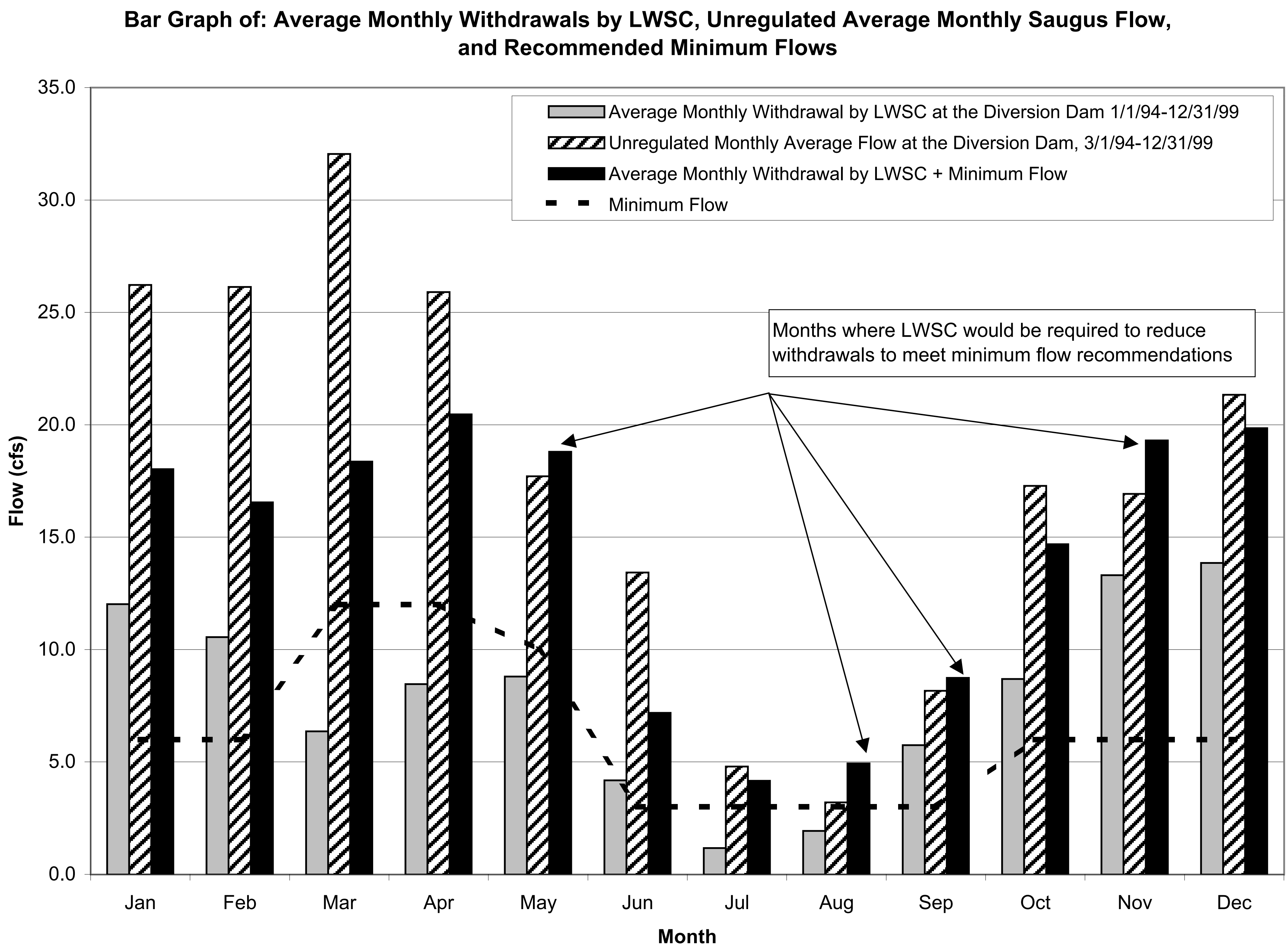

Bar Graph of: Average Monthly Withdrawals by LWSC, Unregulated Average Monthly Saugus Flow, and Recommended Minimum Flows
Average Monthly Withdrawal by LWSC at the Diversion Dam 1/1/94-12/31/99
Unregulated Monthly Average Flow at the Diversion Dam, 3/1/94-12/31/99
Average Monthly Withdrawal by LWSC + Minimum Flow
Minimum Flow
Months where LWSC would be required to reduce withdrawals to meet minimum flow recommendations
Flow (cfs)
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

FIGURE 16.1-4

17.0 References

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